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Evaluation of Booster Seat Suitability for Children of Different Ages and Comparison of Standard and Modified SA103C and SA106C Child Dummies

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16. Abstract

A sled test program was conducted for two purposes: 1) to examine the suitability of shield type booster seats for children spanning the age and size ranges recommended by manufacturers and 2) to compare the performance of standard three and six year old dummies with the performance of the same types of dummies with modified abdomens. All of the tests were conducted on a HYGE sled and approximated FMVSS 213 dynamic test procedures.

For booster seat suitability, nine different booster seats were tested using three dummies, the TNO P3/4, SA103C and SA106C, representing nine month old, three year old and six year old children. Suitability is assessed based on the performance of each dummy with respect to the applicable criteria extracted from FMVSS 213.

For the modified versus standard dummy comparison, the average performance of standard three and six year old dummies are compared with the same types of dummies which have UMTRI modified abdomens. The effects of the presence of the UMTRI abdomen on the performance of each dummy are determined statistically using a sample of eight and seven different booster seats respectively.

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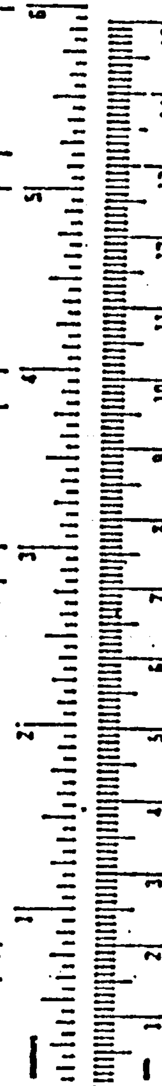
METRIC CONVERSION FACTORS

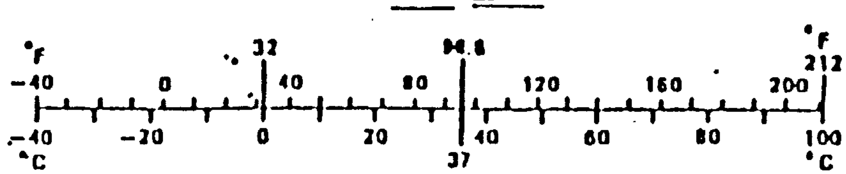
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
		VOLUME		
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	milliliters	mL
fl oz	fluid ounces	30	milliliters	mL
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	5/9 (after subtracting 32)	degrees Celsius	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1000 kg)	1.1	short tons	
		VOLUME		
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5 (then add 32)	degrees Fahrenheit	°F



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Department of Transportation
National Highway Traffic Safety Administration

TECHNICAL SUMMARY

Report Title: Booster Seat Evaluation and Dummy Comparison	February 1990
Report Author(s): Edward C. Hiltner	

A sled test program was conducted for two purposes: 1) to examine the suitability of shield type booster seats for children spanning the age and size ranges recommended by manufacturers and 2) to compare the performance of standard three and six year old dummies with the performance of the same types of dummies with modified abdomens. All the tests were conducted on a HYGE sled and approximated the FMVSS 213 dynamic test procedure.

For the booster seat suitability, nine different booster seats were tested using three dummies, the TNO P3/4, SA103C and SA106C, representing nine month old, three year old and six year old children. Suitability is assessed based on the performance of each dummy with respect to the applicable criteria extracted from FMVSS 213. The tests involving the SA103C were FMVSS 213 compliance tests whereas the tests involving the TNO P3/4 and the SA106C were only approximations of the FMVSS 213 procedure.

Nine-month old: TNO P3/4 -- Booster seats proved generally unsuitable for the nine month old dummy. The dummy was ejected from seven of nine seats (78% rate).

Three-year old: SA103C -- The dummy passed all the applicable FMVSS 213 criteria.

Six-year old: SA106C -- Booster seats generally did not provide adequate restraint for an occupant of this size. In seven of nine seats, the SA106C's head excursion exceeded 32 inches which is the limit imposed on the SA103C in FMVSS 213; two seats also experienced structural failures. These failures occurred with a dummy weighing 46 pounds although the recommended weight range for eight of the nine seats extends to 60 pounds or more. Suitability of these booster seats for children even larger than a six year old, but still within the manufacturers size/weight guidelines, is questionable.

For the modified versus standard dummy comparison, the average performance of standard three and six year old dummies were compared with the same types of dummies which have UMTRI modified abdomens. The effects of the presence of the UMTRI abdomen on the performance of each dummy were examined to determine whether or not they were statistically significant using a sample of eight and seven different booster seats respectively.

Three-year old: SA103C -- The performance of the modified and standard SA103C 3 year old dummies was statistically similar. The differences between the dummies' HIC's and torso accelerations were not statistically significant. The head and knee excursions were, statistically, only marginally affected. The effect on the head excursion, although small, was important because it resulted in the modified dummy's head excursion exceeding 32 inches in five of the eight seats. The modified dummy was ejected twice; the standard dummy was not ejected at all.

<u>Six-year old: SA106C</u> -- The performance of the modified and unmodified SA106C 6 year old dummies was statistically similar. Differences between the dummies' HIC, torso acceleration, head excursion and knee excursion were not statistically significant. In six of the seven seats, both dummies' head excursions exceeded 32 inches. The standard dummy was ejected once; the modified dummy was not ejected at all.

1.0 OBJECTIVE/PURPOSE

The objective of this program and report is to evaluate the dynamic performance of nine different automotive child safety seats (booster seats) over a range of child sizes.

The purpose of the evaluation is to determine if booster seats are generally appropriate or inappropriate for occupants within the size ranges recommended by the manufacturers. The intent is not to rate individual seats or to rank them relative to one another for a given occupant.

An additional objective is to repeat some booster seat evaluation tests that were previously conducted using dummies with modified abdomens. The purpose is to determine whether the modified abdomens significantly affected the dummies' responses in booster seats.

1.1 Background

Currently, Federal Motor Vehicle Safety Standard Number 213 (FMVSS 213) uses the six-month-old dummy for seats labelled for children under 20 pounds and the three-year-old dummy for seats labelled for children between 20 and 50 pounds to test the compliance of child safety seats. The six-month old infant is used in dynamic tests with rearward facing carriers; the three-year-old is used to certify different types of seats that vary greatly in design.

Many child safety seats are being marketed for a broad range of sizes including the three-year-old. The 50th percentile three-year-old weighs approximately 33 pounds and stands 38 inches tall. There are seats on the market that are being recommended for children ranging from 20 pounds to 70 pounds. Based on weight alone, that would approximately span the range represented by 50th percentile nine-month-old and 50th percentile 10-year-old children [1][1].

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[1]Numbers in brackets represent references at the end of this report.

This raises the question: how suitable are these seats for sizes of children other than the three-year-old, especially those at the extremes of the ranges recommended by the manufacturers? This is an issue not currently addressed by the FMVSS 213. The biomechanical tolerances of children at either end of this range (nine months to 10 years old) are drastically different from one another. Infants are developmentally immature and, generally, are not able to endure localized impact or loading that is typical of forward facing restraints [2]. At the other extreme, it is not clear how well older (taller and heavier) children would fare with the excursion limits imposed on the three-year-old dummy or whether it is appropriate to apply them. The additional inertial loading of a heavier child also increases the probability of structural failure.

One type of seat which is popular for its flexibility in accommodating a range of occupant sizes is the small shield booster seat. This type of seat is marketed to bridge the gap between toddler safety seats and adult size automobile safety belts. The age and size restrictions suggested by manufacturers vary from seat to seat. The majority of the booster seats examined in this program are for children between 30 and 60 pounds with a few as low as 20 pounds and as high as 70 pounds. Few of these seats stipulate age or specific height restrictions other than the maximum recommended seated height. In FMVSS 213, booster seats are only tested with the three-year-old dummy.

By accommodating a range of occupant sizes, a potential for misuse or misapplication exists for many of these booster seats. Manufacturers market their seats for a broader range of occupants than is currently covered in existing regulations. This project attempted to look at the suitability of these seats using available dummies of various sizes and examine previous work done with a similar intent.

2.0 TEST METHODOLOGY

The test methodology consisted of 1) calibrating the nine-month, three-year and six-year-old dummies and 2) conducting a series of dynamic crash simulations on a HYGE sled using these three dummies in nine different booster type safety seats. The tests involving the nine-month-old and six-year-old dummies were done at TRC; those involving the three-year-old dummy were done at Calspan in Buffalo, New York.

The test procedures for the three-year-old (SA103C) unmodified dummy conformed to the specifications in FMVSS 213 because they were compliance tests. The test procedures used with the modified three-year-old, modified and unmodified six-year-old (SA106C), and nine-month-old (TNO P3/4) were based on but did not strictly adhere to the specifications in FMVSS 213. (See section 2.2.2 for deviations from FMVSS 213.) This section of the report highlights the aspects of the test procedure used to evaluate booster seats and explains deviations from the standard specifications.

2.1 Dummy Calibrations

The calibration tests performed before and after the TRC sled series for the nine-month old and the SA106C are not standardized procedures because these dummies are not specified as test devices in Part 571.213 or Part 572. The recommended procedures and specifications for both dummies are, however, very similar to those used for the three-year-old in FMVSS 213. The calibration results for the TNO P3/4 and SA106C dummies are presented in this report. The calibration results for the SA103C dummy can be obtained from Calspan. (Calspan report number 572CCAL88066, which contains pre- and post-test series calibration data.)

2.1.1 TNO P3/4

Instrumentation

The instrumentation used in this dummy consisted of three Endevco 7264-2000 uniaxial, piezoresistive accelerometers in triaxial arrangements in both the head and thorax. The head and thorax accelerometer mounting schemes were developed for the purposes of this project, and do not represent a standardized configuration for this dummy.

The head was instrumented with three Endevco 7264's mounted to the Nylon transducer mounting block by means of a special adaptor. The accelerometer assembly was designed to emulate the older (now obsolete) Endevco 7231 sealed triaxial accelerometer which had been used at one time in the three-year-old dummy. The resulting locations of the seismic masses of the three accelerometers were approximately 0.4 inches from the intersection point defined by the midsagittal plane of the head and the axial line passing through the centerline of the two screws attaching the Nylon accelerometer mount (transducer mounting block) to the head. Two modifications were made to the dummy to accommodate the instrumentation: 1) a groove and two threaded holes were cut in the Nylon mounting block for the 7264-2000 adaptor block (Figures 2.1 through 2.4); 2) the threaded nipple at the end of the spine cable which passed through the neck and protruded into the head cavity was shortened to prevent interference with the accelerometers during head rotation.

The thorax was instrumented with three Endevco 7264-2000 accelerometers using an Endevco model 7954 triaxial adaptor block. The 7954 block and 7264 accelerometers were mounted to a .25 inch aluminum plate shown in Figure 2.5. The instrumentation package attached to the interior of the thoracic cavity on a mounting surface provided on the anterior face of the dummy's rigid thoracic spine.

The reason for using a different accelerometer adaptor in the thorax than was used in the head was that A/P clearance between the interior chest wall and the anterior face of the thoracic spine was too shallow for the special accelerometer adaptor. Compression of the chest wall during impact even further limits the clearance for instrumentation. The Endevco 7954 block with a 7264-2000 accelerometer is 0.58 inches in depth; the special adaptor with the same accelerometer is 1.18 inches in depth.

Calibration Tests

Head and torso impact tests and the lumbar flexion test were the only calibration tests performed on the nine-month old dummy. The impact tests were performed before and after the sled test series. The lumbar flexion test was

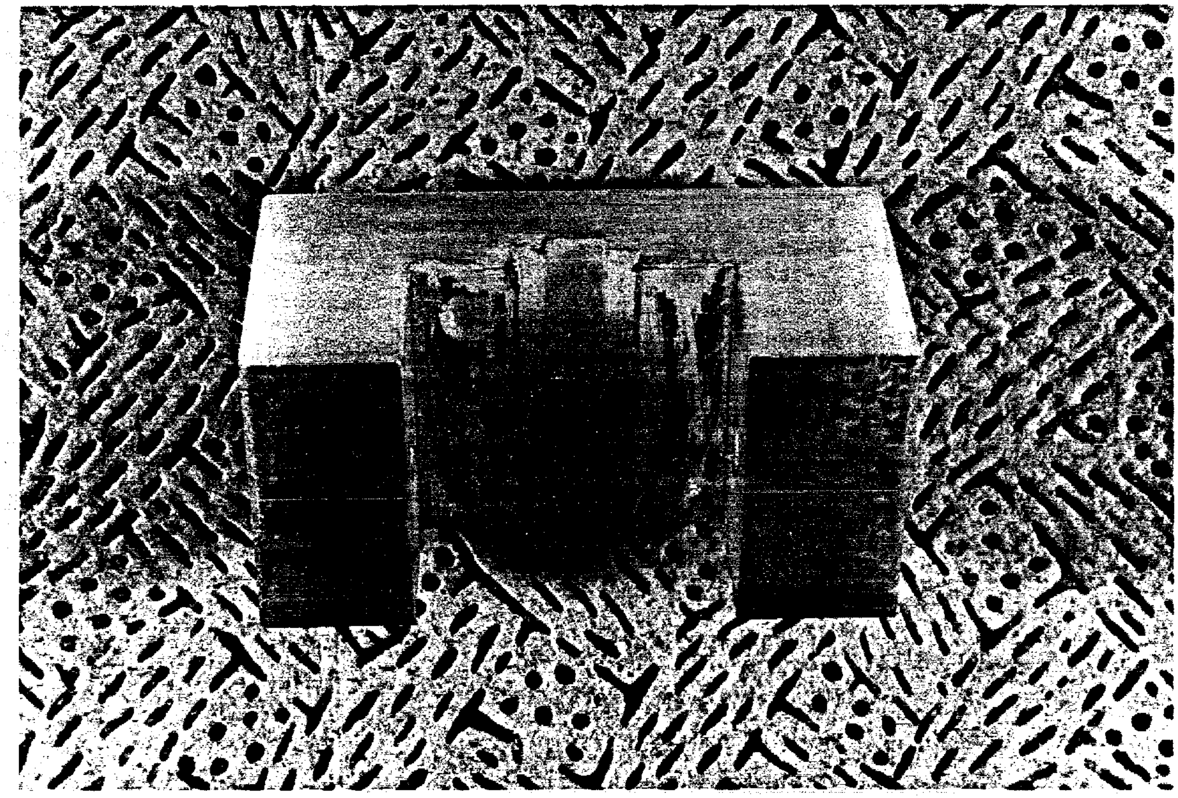


FIGURE 2.1 -- TNO P3/4 Head Transducer Mounting Block

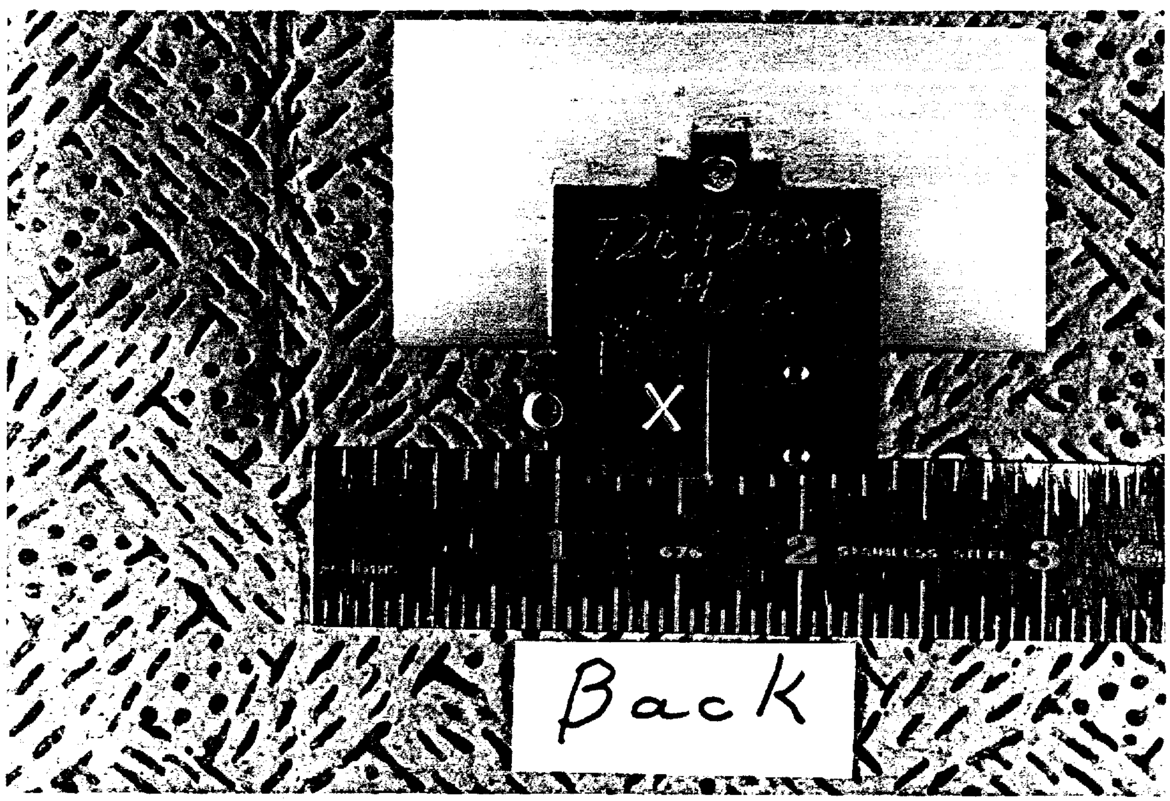


FIGURE 2.2 -- TNO P3/4 Head Transducer Mounting Block

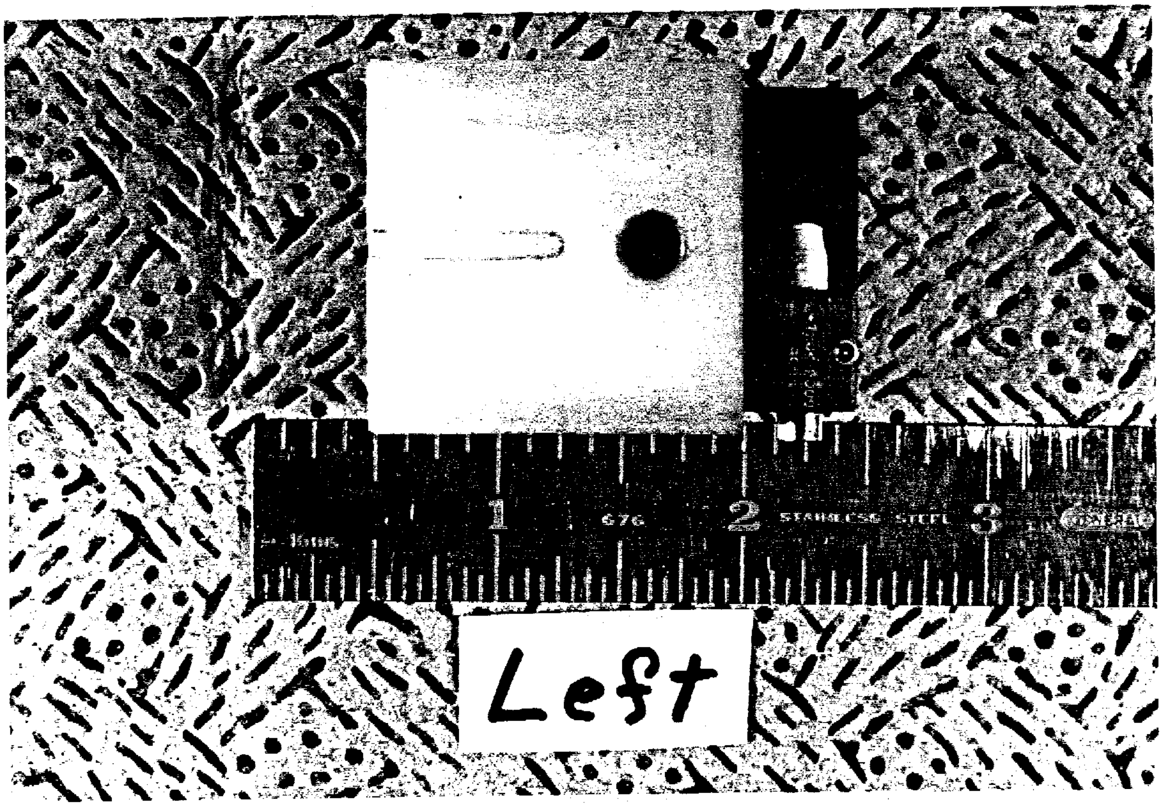


FIGURE 2.3 -- TNO P3/4 Head Transducer Mounting Block

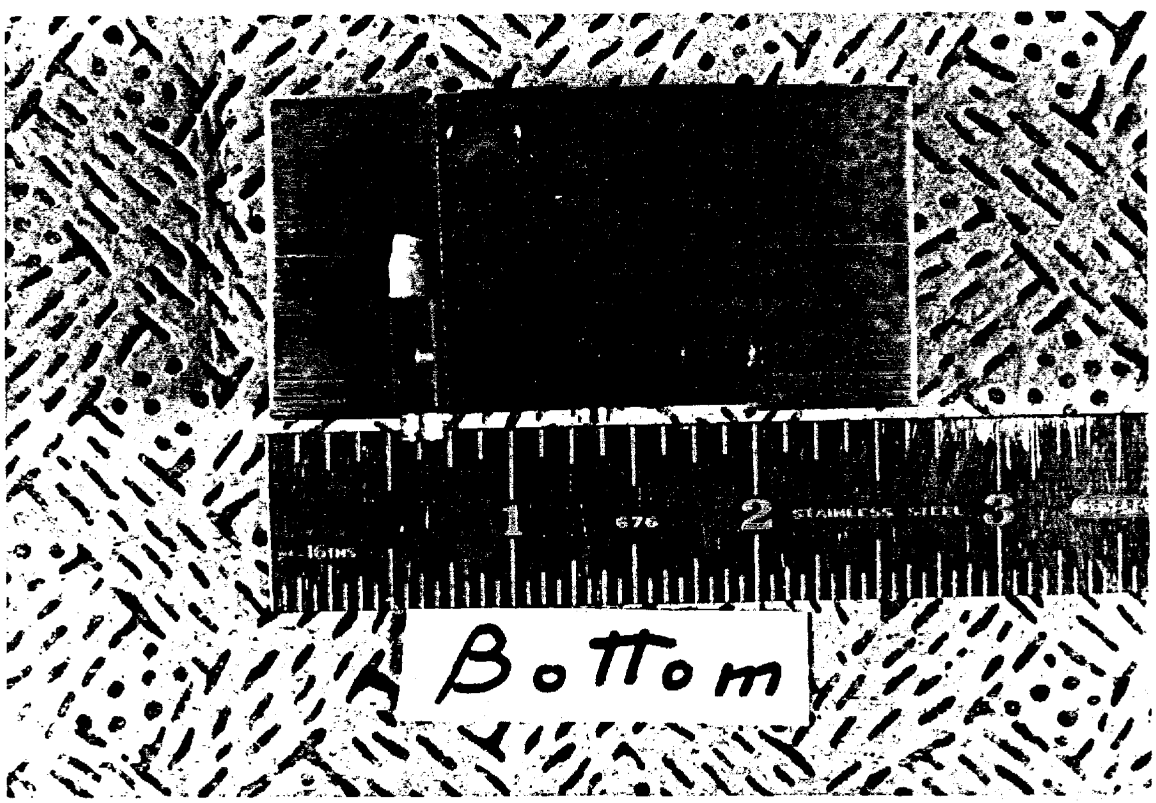


FIGURE 2.4 -- TNO P3/4 Head Transducer Mounting Block

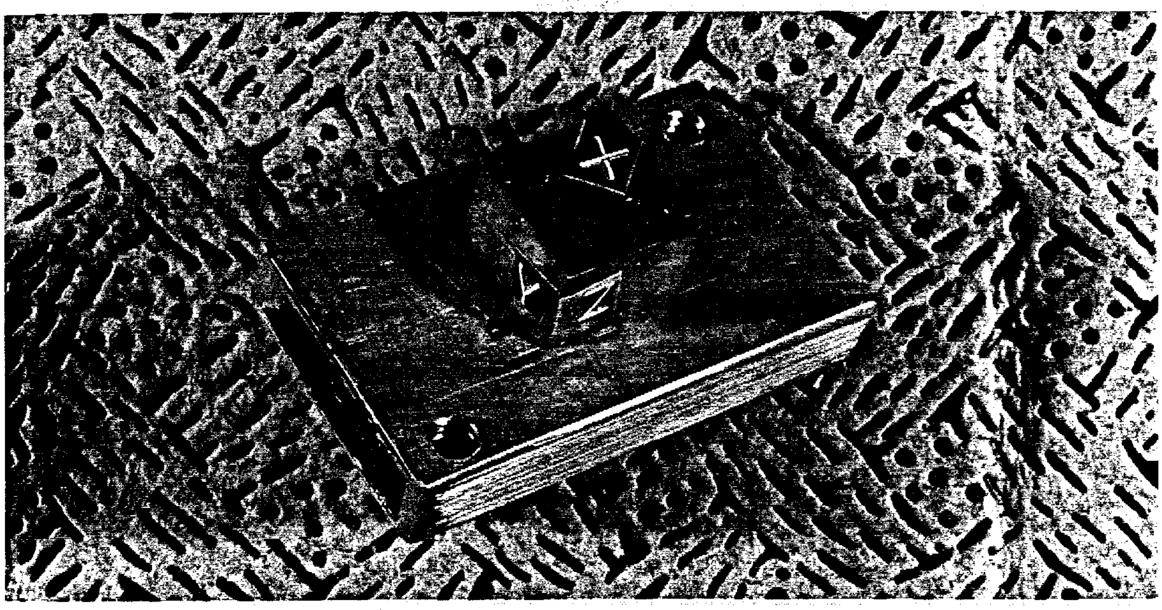


FIGURE 2.5 -- TNO P3/4 Chest Transducer Mounting Block

performed only after the sled series. The specific calibration procedures and test results are provided in Appendix A.

Head/neck extension and flexion pendulum tests were not performed because of the extent of modifications of the certification test fixtures which would have been necessary.

The nine-month old's primary head and chest impact responses were slightly higher than the target levels before and after sled testing. The peak force at the maximum lumbar flexion angle of 40 degrees was higher than the target levels.

2.1.2 SA106C

Instrumentation

The instrumentation used in this dummy consisted of three Endevco 7264-2000 accelerometers in triaxial arrangements in both in the head and thorax. Neither femur nor neck load cells were used in the dummy.

Calibration Tests

Calibration tests were performed before and after the sled test series using the procedures developed by the Calspan Corporation in a program intended to evaluate the performance repeatability of the SA106C, six-year-old dummy [3]. The recommended performance specifications for this dummy were obtained from the Calspan report entitled "Evaluation of the Performance of Child Restraint Systems" [4]. Head impact tests as well as head/neck flexion and extension tests were performed. Femur impact tests were not performed because the femur load cells were not used in this test series. The calibration specifications and test results are provided in Appendix A.

The dummy's peak head impact response exceeded the recommended response limits in the calibration tests before and after the sled test series. However, the pendulum velocity was near the upper limit of the 7.0 ± 0.1 fps velocity corridor. The pre and post sled test torso impact responses fell within the recommended limits. The lumbar flexion responses were slightly less than the recommended levels.

2.2 Sled Testing

The sled tests conducted at TRC/VRTC were performed on a HYGE accelerator which simulates vehicle impact conditions.

2.2.1 Test Matrix

Nine seats, seven of which were available to consumers at the beginning of this project, were chosen for testing. Three dummies, the TNO P3/4, SA103C and SA106C representing nine-month old, three-year-old and six-year-old children were used to span the age and anthropometry ranges for which these seats are typically recommended and/or used. The test matrix simply combines the nine seats with the three dummies using a fixed set of test conditions resulting in 27 separate tests. The test conditions for this matrix are presented and briefly discussed in the following section, 2.2.2.

Table 2.1 lists the seats tested including the age and anthropometry restrictions recommended by the manufacturers. Table 2.2 lists the dummies used and provides some pertinent anthropometric data.

TABLE 2.1 -- Booster Seat Occupant Size Ranges

NO	BOOSTER SEAT		MANUFACTURER RECOMMENDED:		
	MANUFACTURER	NAME/MODEL #	CHILD WEIGHT	CHILD HEIGHT (1)	AGE
1	Gerico (Gerry)	Voyager/#660-590	30 - 60 #	33" - 51"	N/A
2	Ford	Tot Guard	20 - 50 #	> 35" < 46" > 19" < 28" (2)	at least 1 yr
3	Pride-Trimble	Click N' Go/#891	25 - 65 #	33" - 51"	3 - 8 yrs
4	Evenflo	Sightseer/#472100A	30 - 60 #	(3) (approx 48")	N/A
5	Strolee	Quick Click/ #605	30 - 70 #	< 56"	N/A
6	Cosco	Explorer I/#2399C	30 - 60 #	(3)	N/A
7	Kolcraft	Tot-Rider Quikstep #198-100	20 - 60 #	(3)	N/A
8	Evenflo	Booster/#47147	30 - 60 #	< 48"	N/A
9	Century	Commander/#4835	20 - 65 #	(3)	2 - 10 yrs

(1) Child height is standing height unless otherwise indicated
(2) Seated height
(3) Mfr recommends the midpoint of the head shall not exceed the top of the seat

TABLE 2.2 -- Dummy Anthropometry

Child Dummy	Standing Height (inches)	Seated Height (inches)	Weight (pounds)
Nine-month TNO P3/4	27.5	17.9	20.0
Three-year SA103C	38.4	22.5	32.2
Six-year SA106C	47.5	25.6	45.5

An inconsistency is observed in Table 2.1 in the way manufacturers classify booster seats for differing sizes of children. All of the manufacturers use child weight as a criterion but there was no consistency regarding height restrictions although this is clearly required in Part 571.213. Because of this, it is plausible that a seat might be misused. Therefore, it was deemed appropriate to investigate each seat's performance over the selected range of occupant sizes.

2.2.2 Test Conditions

The test conditions used for this project generally came from the Part 571.213 "Dynamic Test Procedure" specifications. The following test conditions very briefly summarize the nature of the sled tests:

1. The sled buck and seat was accelerated to a peak velocity of approximately 29.7 miles per hour with the acceleration pulse shown in Figure 2.6.

2. The manual, non-retracting (Type I) lap belts were tightened to an approximate tension of 12 to 15 pounds before each test run and replaced after each test.

The measurements taken during each test run are summarized as follows:

1. X,Y, and Z accelerations at the head's center of gravity.

2. X,Y, and Z accelerations in the torso.

3. Inboard and outboard belt tensions.

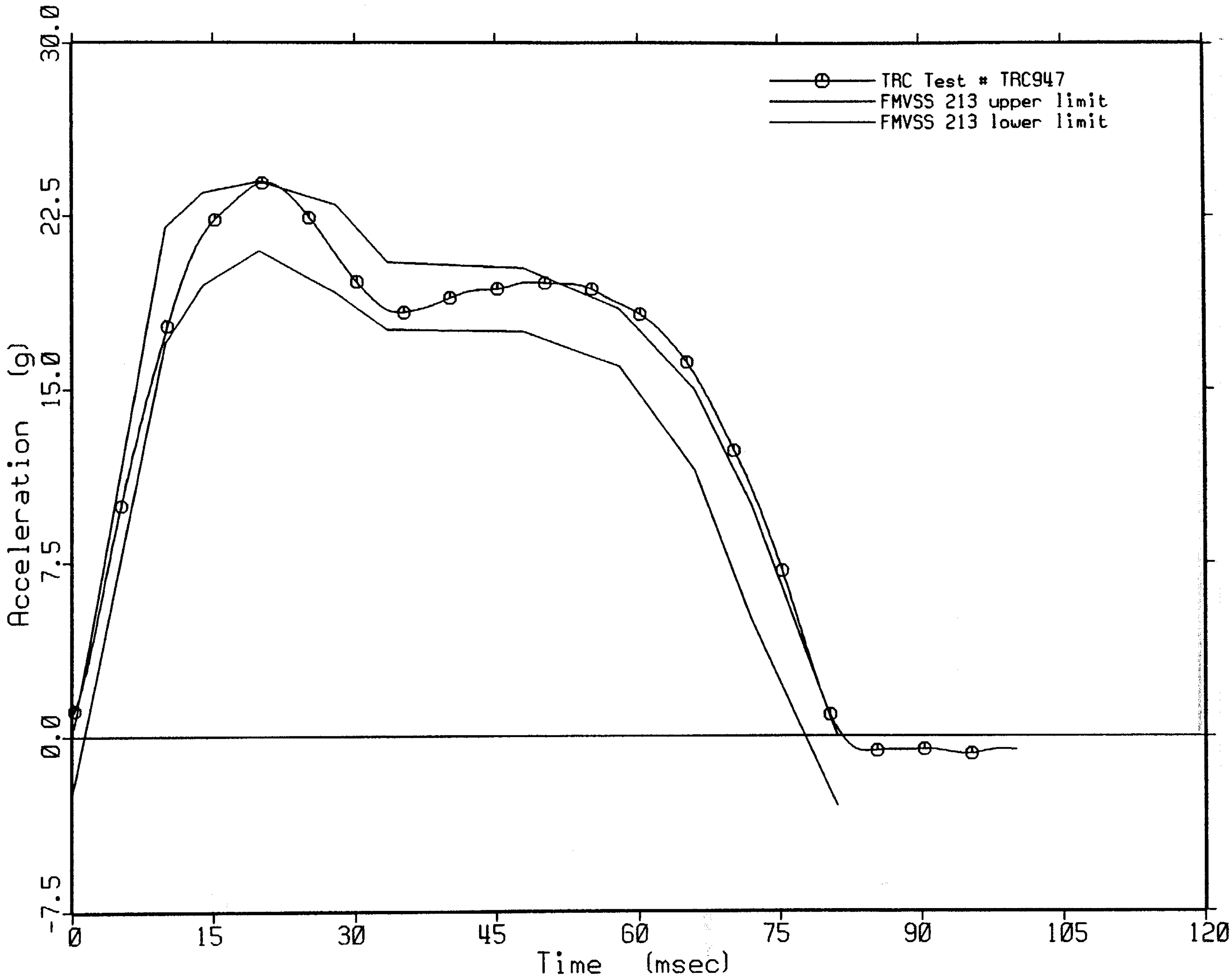
4. Two high speed cameras per side (for each dummy) for accurate head and knee excursion measurements and overall dummy and booster seat kinematics.

5. Sled velocity and acceleration.

The following exceptions and deviations were made in the FMVSS 213 test procedure:

1. Two dummies were tested, rather than one, in a side by side configuration on the FMVSS 213 seat.

2. The "Buckle release test procedure" was omitted.



HYGE Sled Acceleration

FIGURE 2.6

3. The SA106C six-year-old and TNO P 3/4 nine-month old dummies were used in addition to the specified SA103C three-year-old dummy. The six-month old dummy was not used.

4. The positioning procedure for the three-year-old dummy was applied directly to each of the other two dummies with no modifications.

5. The same seat cushion foam was used throughout the test series. The compression/deflection performance after the end of the test series, was found to be approximately 5 to 10% less stiff than the specifications required.

The listed items are the prime differences between these tests and the FMVSS 213 compliance tests. The project was not intended to precisely duplicate compliance tests, but rather to approximate the conditions for an assessment of how smaller and larger dummies would perform in booster seats normally tested only with the three-year-old.

The test conditions were fixed throughout the sled test series. The only variables in the matrix were the dummies and the booster seats.

3.0 RESULTS

The test results and discussion for the booster seat evaluation are presented in Sections 3.1 and 3.2. The results and discussion for the modified versus standard dummy comparisons are presented in Sections 3.3 and 3.4.

3.1 Booster Seat Evaluation Results

The sled tests were conducted as specified in 2.2. Table 3.1 summarizes the results obtained from those tests. Included in the table are the results from the comparable tests performed at the Calspan Corporation using the SA103C three-year-old dummy. The belt loads, head resultant accelerations and torso

TABLE 3.1 -- Booster Seat Evaluation Results

	Test #	Child Restraint Type	Child Restraint Type Code	Peak Belt Tension Inboard (lbs)	Peak Belt Tension Outboard (lbs)	Peak Head Resultant Acceleration (g) (1)	HIC	Peak Head Excursion (in)	Peak Torso Resultant Acceleration (g) (1)	Peak Knee Excursion (in)	Ejection ?
TNO P3/4	942	Gerry Voyager	GV	1308	794	42.3	322	28.7	51.1	(2)	Y
NINE-MONTH	943	Ford Tot Guard	FTG	943	605	48.4	389	28.0	40.4	(2)	Y
OLD	944	Pride-Trimble Click N' Go	PTCNG	787	543	58.2	465	23.9	43.3	(2)	Y
	945	Evenflo Sightseer	ES	888	596	44.8	283	21.8	40.9	(2)	Y
	946	Strolee Quick Click	SQC	764	721	43.7	299	25.6	35.5	20.6	
	947	Cosco Explorer I	CE I	774	534	51.9	379	23.6	36.3	(2)	Y
	948	Kolcraft Tot-Rider Quickstep	KTRQS	746	604	57.3	397	23.4	34.7	8.3	Y
	949	Evenflo 7 Year Booster	EB	684	518	37.9	238	24.7	35.3	(2)	
	950	Century Commander	CC	725	501	44.7	314	24.7	37.4	(2)	Y
			AVERAGE	847	602	47.7	343	24.9	39.4	19.5	
			STANDARD DEV.	191	98	6.9	70	2.2	5.3	*	
SA103C	5127	Gerry Voyager	GV				742	31.6	36.2	29.2	
THREE-YEAR	5126	Ford Tot Guard	FTG				792	31.7	38.4	27.5	
OLD	5125	Pride-Trimble Click N' Go	PTCNG				515	31.2	27.2	22.3	
	5128	Evenflo Sightseer	ES				566	27.4	34.4	24.1	
	5122	Strolee Quick Click	SQC				462	31.8	26.2	24.6	
	5131	Cosco Explorer I	CE I				769	28.5	33.1	23.6	
	5121	Kolcraft Tot-Rider Quickstep	KTRQS				467	29.8	26.7	22.3	
	5130	Evenflo 7 Year Booster	EB				736	28.3	31.3	24.5	
	5129	Century Commander	CC				619	29.8	29.4	23.3	
			AVERAGE				630	30.0	31.4	24.6	
			STANDARD DEV.				133	1.7	4.4	2.3	
SA106C	942	Gerry Voyager	GV	1538	1209	66.9	650	34.7	44.9	33.6	
SIX-YEAR	943	Ford Tot Guard	FTG	1296	1377	57.6	530	27.0	35.8	34.2	
OLD	944	Pride-Trimble Click N' Go	PTCNG	1021	990	51.9	435	33.8	26.5	27.7	
	945	Evenflo Sightseer	ES	924	1074	61.7	434	30.5	35.7	26.9	
	946	Strolee Quick Click	SQC	1089	1050	46.3	365	40.7	25.5	30.0	Y
	947	Cosco Explorer I	CE I	836	833	64.1	796	33.1	35.4	26.5	
	948	Kolcraft Tot-Rider Quickstep	KTRQS	724	918	41.0	291	33.6	22.2	28.6	
	949	Evenflo 7 Year Booster	EB	795	803	44.4	272	36.7	27.1	28.5	
	950	Century Commander	CC	778	721	64.0	674	34.0	29.5	26.9	
			AVERAGE	1000	997	55.3	494	33.8	31.4	29.2	
			STANDARD DEV.	271	208	9.7	181	3.8	7.1	2.8	

(1) Peak pulse duration of 3 msec (2) knee target obscured by seat

accelerations from the Calspan tests were not available for inclusion in this table.

The peak torso and head resultant accelerations reported in Table 3.1 are 3 msec in duration.

The results shown in Table 3.1 are also presented in bar graphs in Figures 3.1 through 3.8. In the odd numbered figures (3.1, 3.3, 3.5 & 3.7) the Head Injury Criteria (HICs), head excursions, resultant torso accelerations (3 msec interval clip), and knee excursions are presented for each dummy in each seat. The even numbered figures (3.2, 3.4, 3.6 & 3.8) show the ranges of responses for each dummy in the sample of booster seats as a group.

Some of the performance criteria which the SA103C must meet to comply with the Part 571.213 Standard briefly are :

1. head excursion $\leq$ 32 inches from the SORL,

2. knee excursion $\leq$ 36 inches from the SORL,

3. resultant torso acceleration $\leq$ 60 g's for a time interval of $t \leq 3$ msec,

4. HIC $\leq$ 1000,

5. retention of the dummy's torso within the safety seat system,

6. the child seat should exhibit no complete separation of any load bearing structural element,

7. if adjustable to different positions, remain in the same adjustment position during testing as it was before testing.

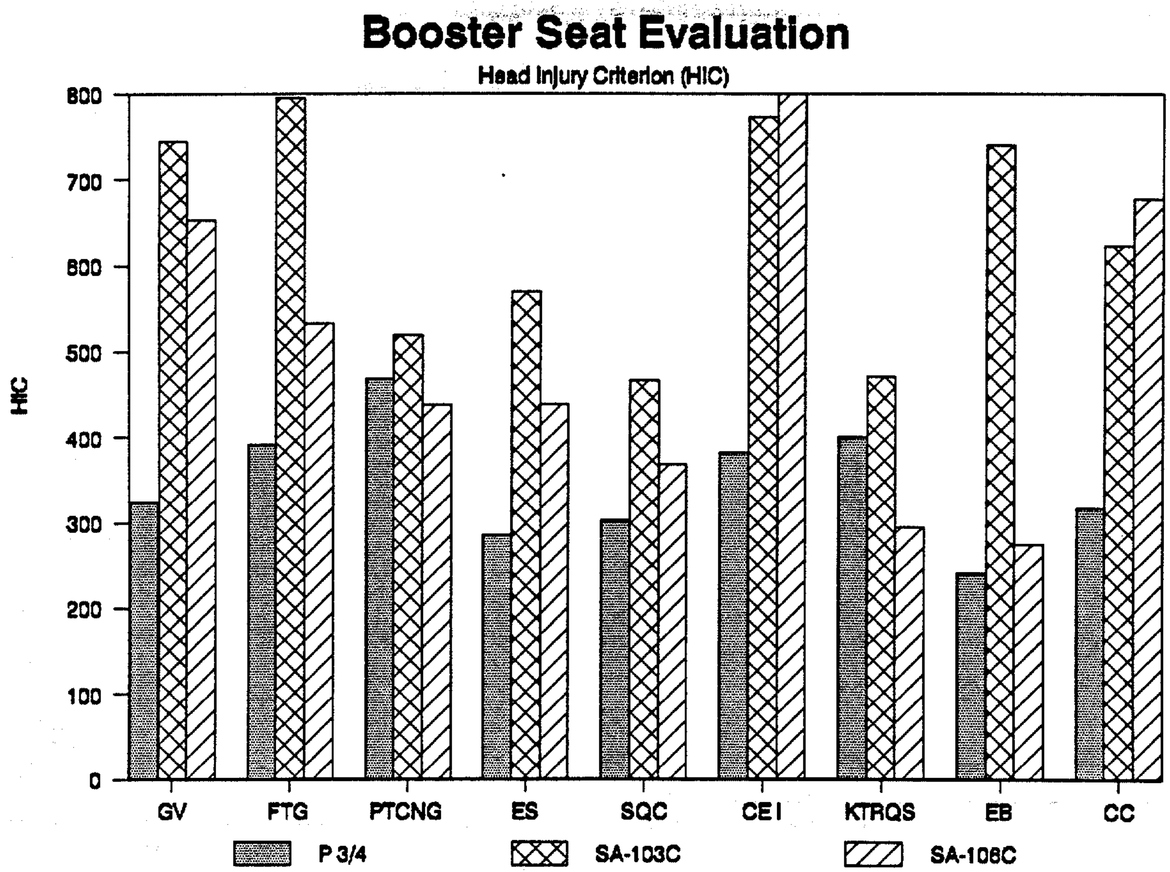


FIGURE 3.1 — Head Injury Criterion

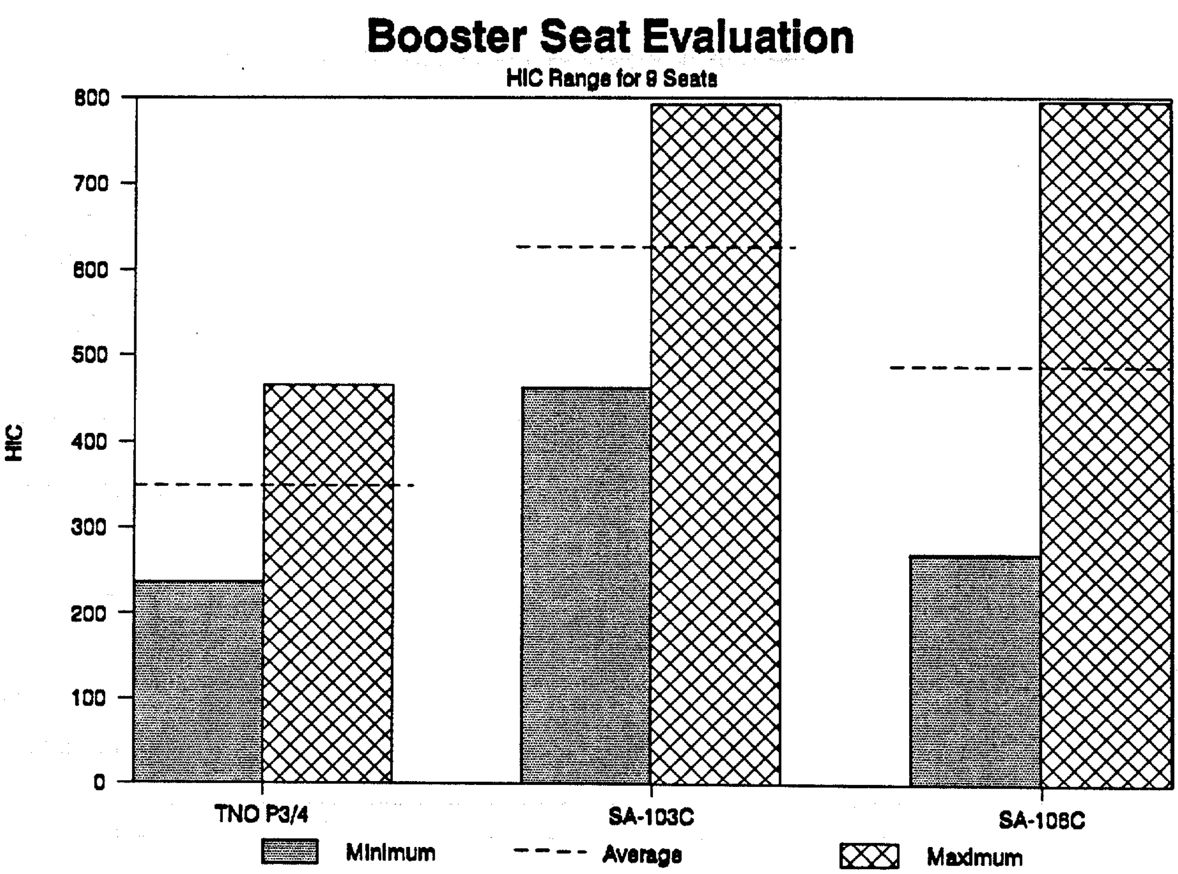


FIGURE 3.2 — Head Injury Criterion Range for Each Dummy

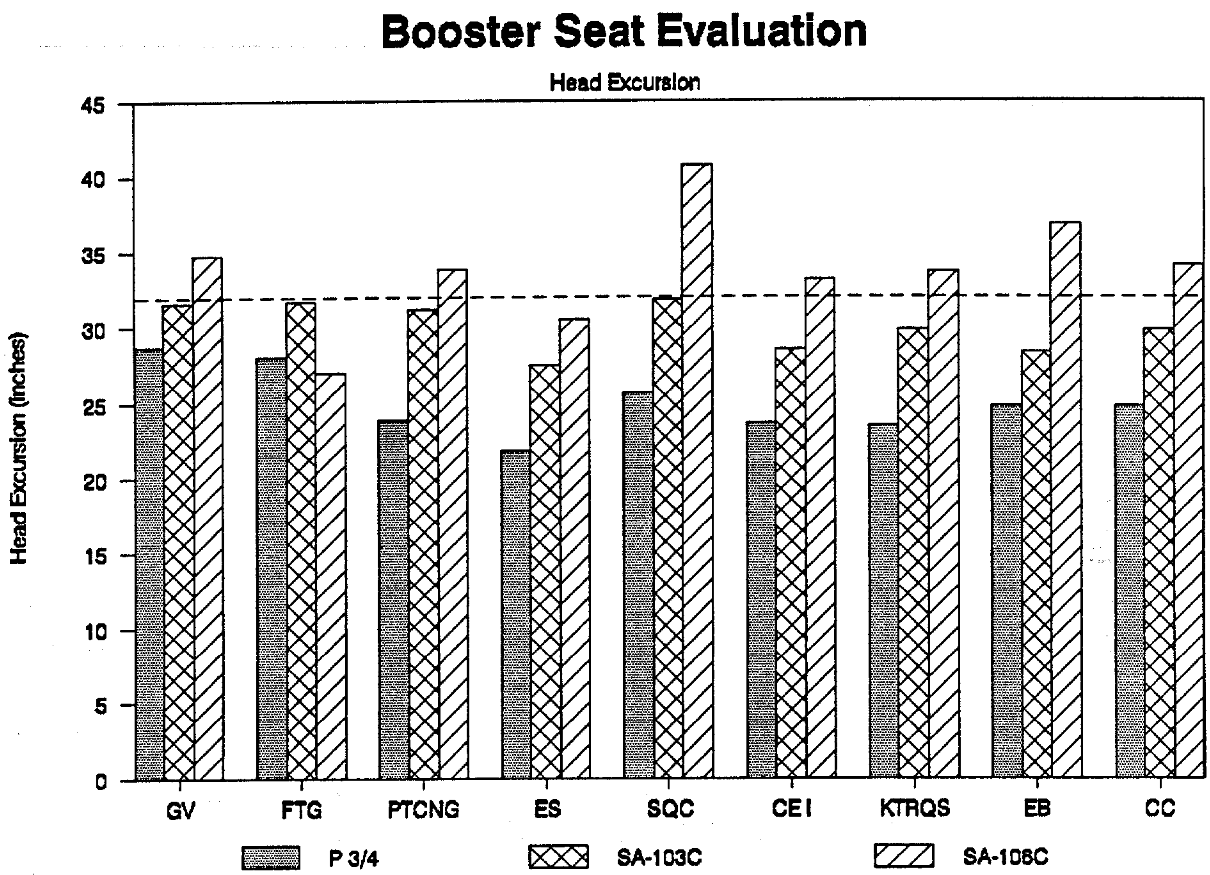


FIGURE 3.3 — Head Excursion

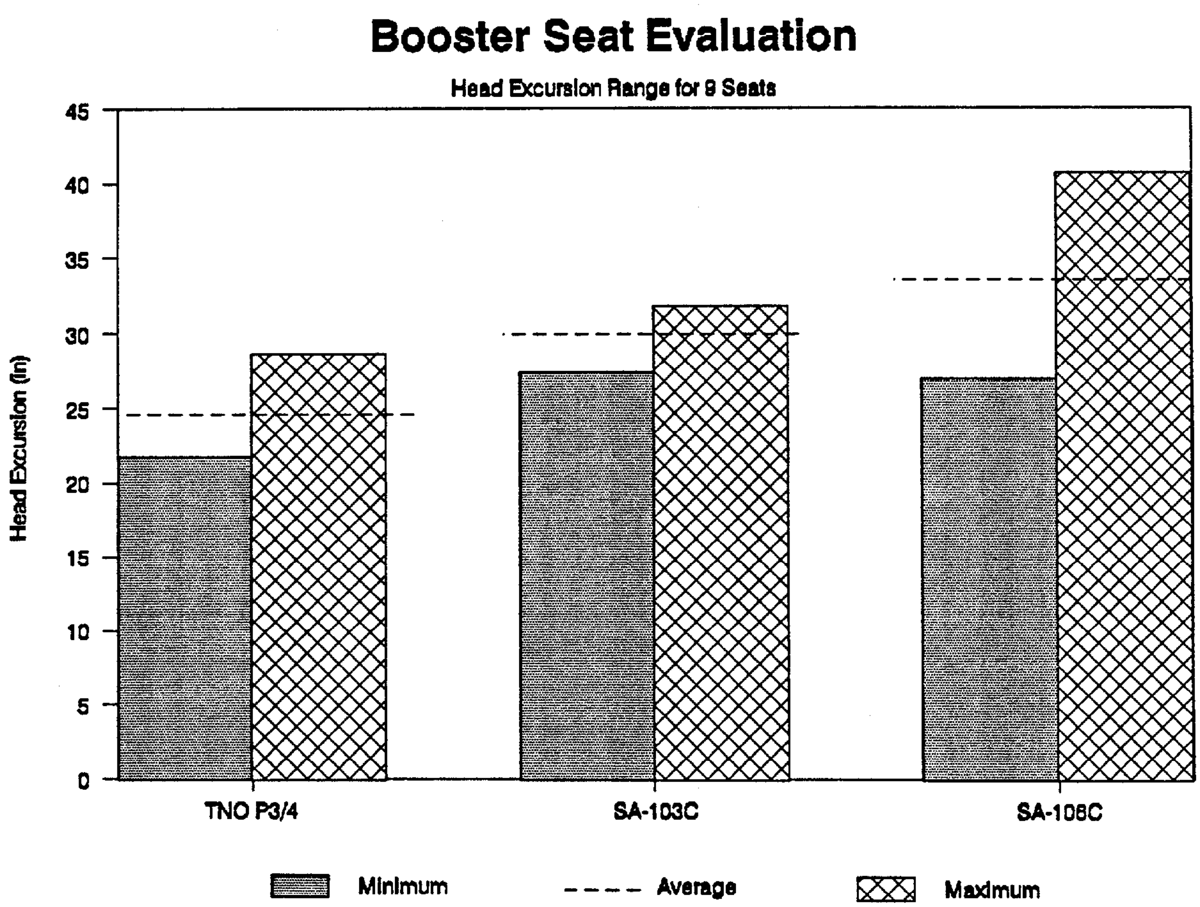


FIGURE 3.4 — Head Excursion Range for Each Dummy

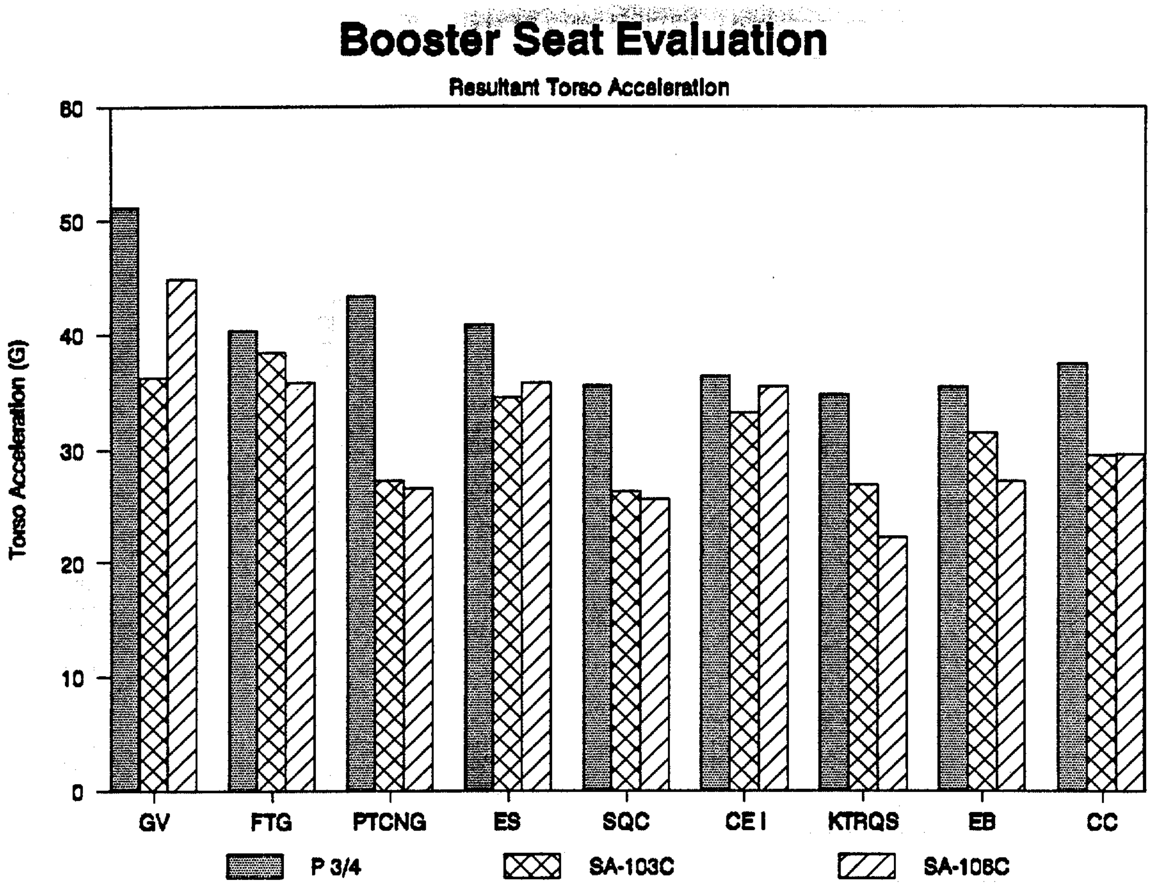


FIGURE 3.5 — Resultant Torso Acceleration

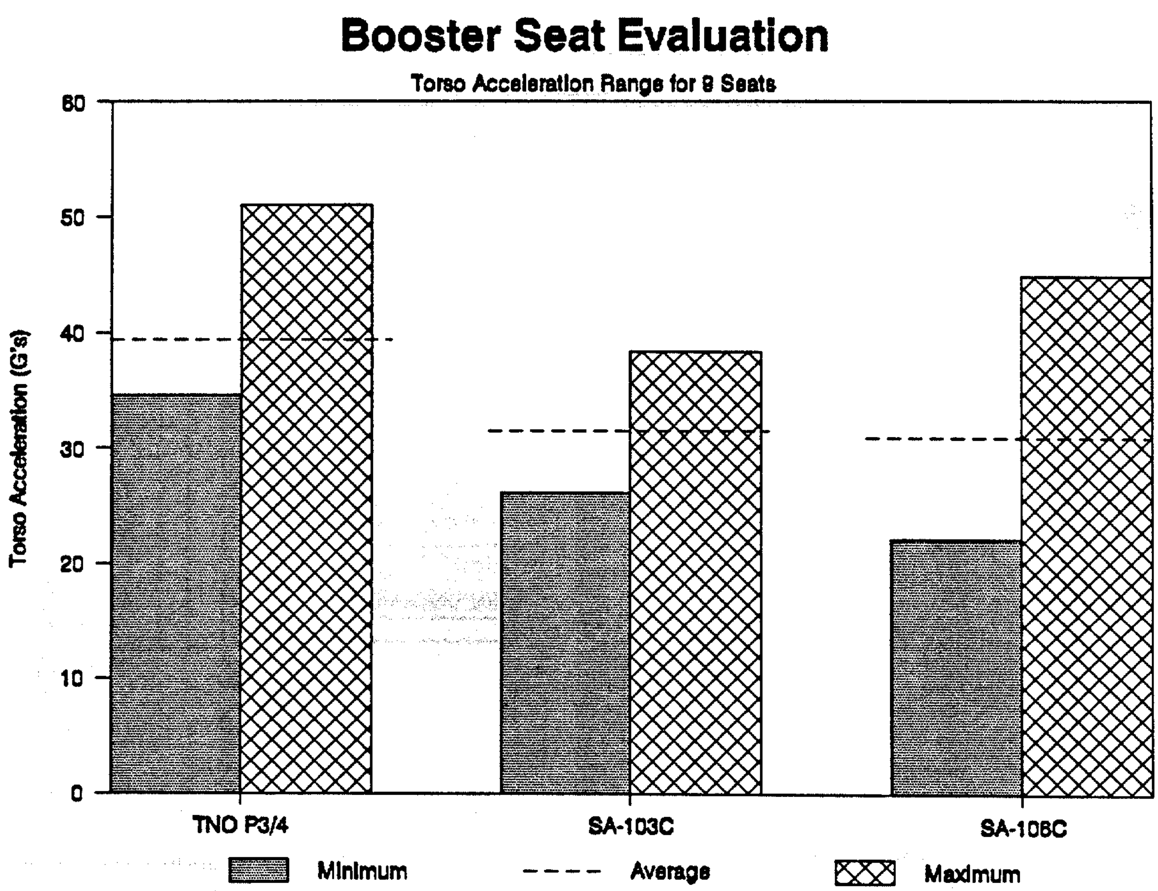


FIGURE 3.6 — Resultant Torso Acceleration Range for Each Dummy

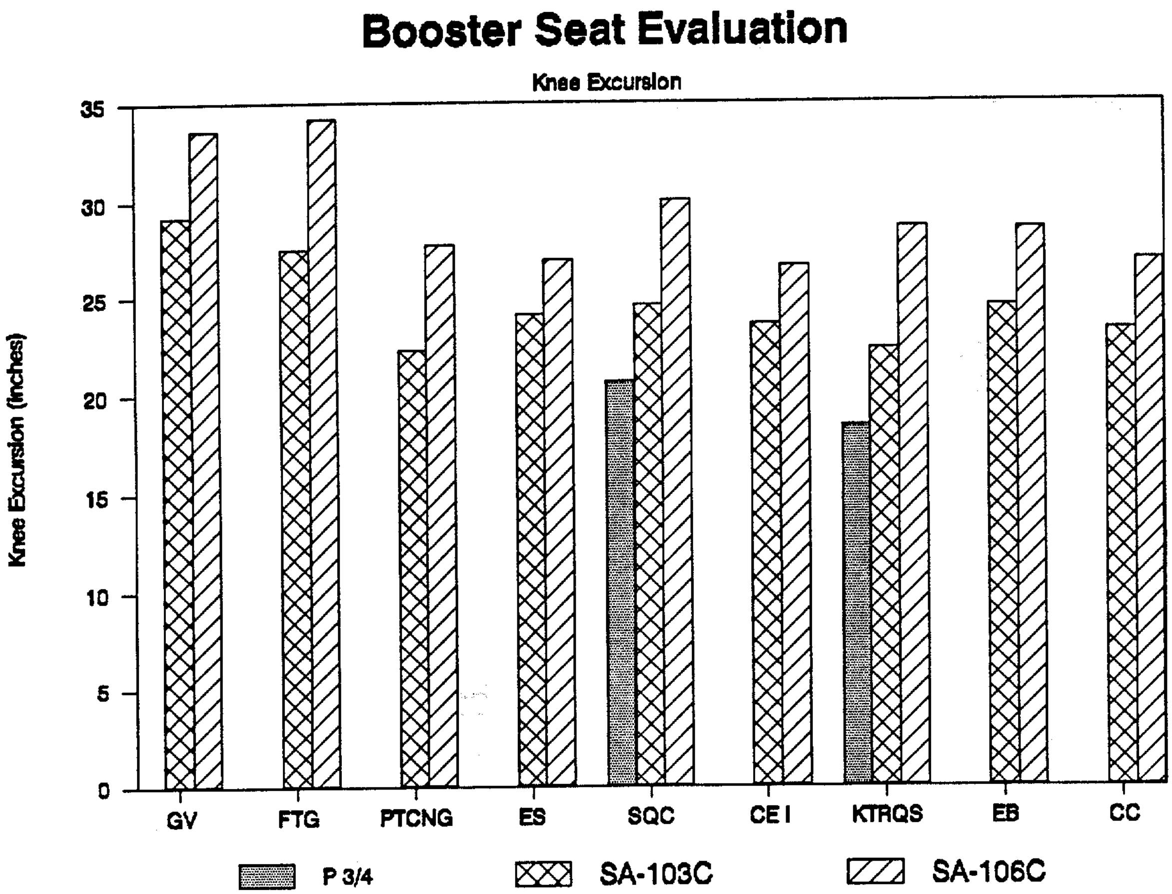


FIGURE 3.7 — Knee Excursion

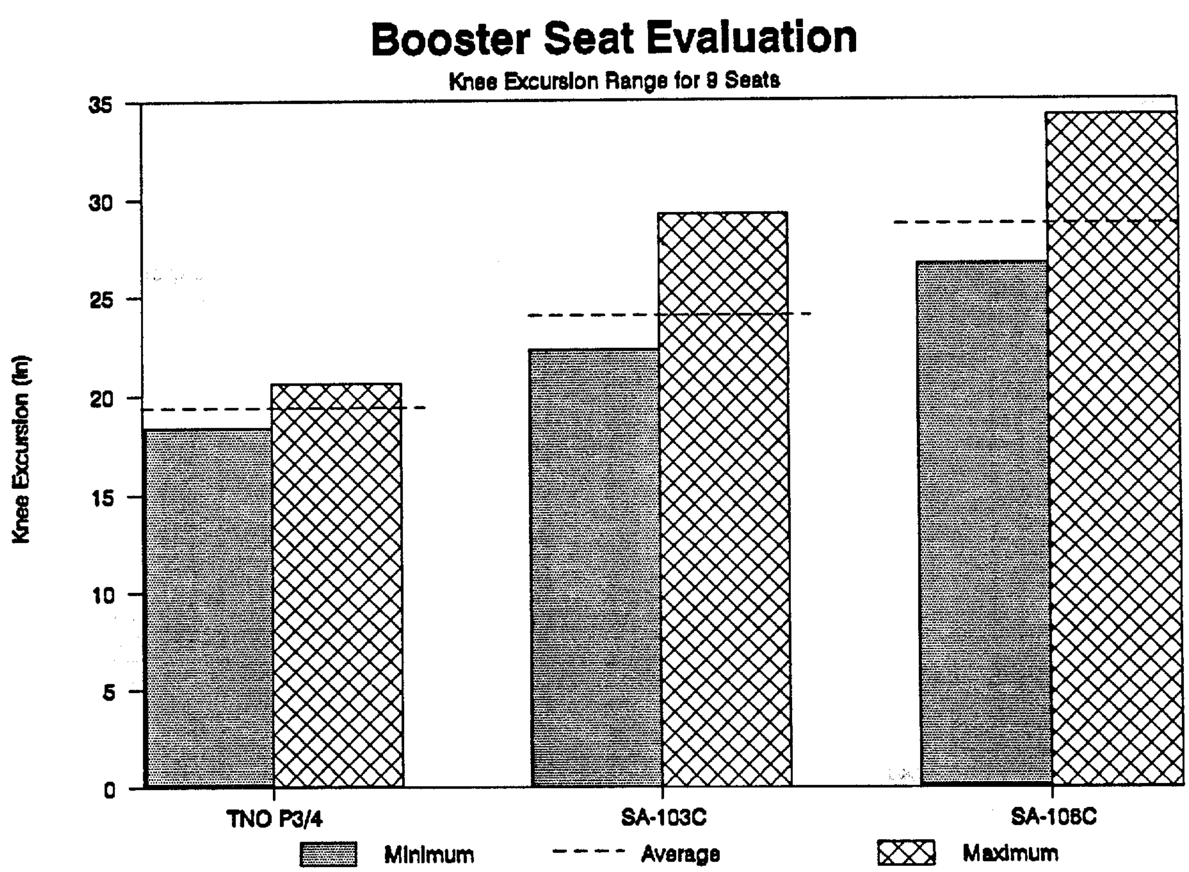


FIGURE 3.8 — Knee Excursion Range for Each Dummy

These criteria were applied, without adjustment or scaling, to each of the three dummies.

3.2 Discussion of Booster Seat Evaluation Results

The results of the booster seat evaluation portion of this project are discussed in this section: each dummy individually in Section 3.2 and then the three dummies comparatively in Section 3.3.

3.2.1 TNO P3/4

Ejections

The dummy was ejected from the booster seat during the rebound phase in seven of nine tests. Typically, the dummy rolled over the shield then vaulted upward as the booster rebounded from the compressed seat cushion. A tether had been attached to the dummy's ankle to prevent complete ejection from the sled. To illustrate the ejections, a photographic series of a typical test is shown in Figures 3.9 through 3.13 (note the photo in Figure 3.11 which coincides with the end of the forced acceleration pulse at approximately 80 msec).

The rebound ejections of the dummy are attributable largely to the combination of its anthropometry and the booster seat geometry; specifically, the length of the dummy's legs and the position of its center of gravity in the seated position relative to the position of the booster seat shield. The nine-month old's seated c.g. is proportionally higher and the leg lengths are shorter relative to an older child [2]. Unhindered by its legs, the nine-month old dummy tends to roll over the shield and eject from the seat during rebound.

There was initially some uncertainty whether the ejections were unrealistically exacerbated by the braking deceleration of the sled after the end of the positive acceleration pulse ($t \geq 80$ msec). The sled buck was braked continuously at approximately .36 g's from the onset of the acceleration pulse

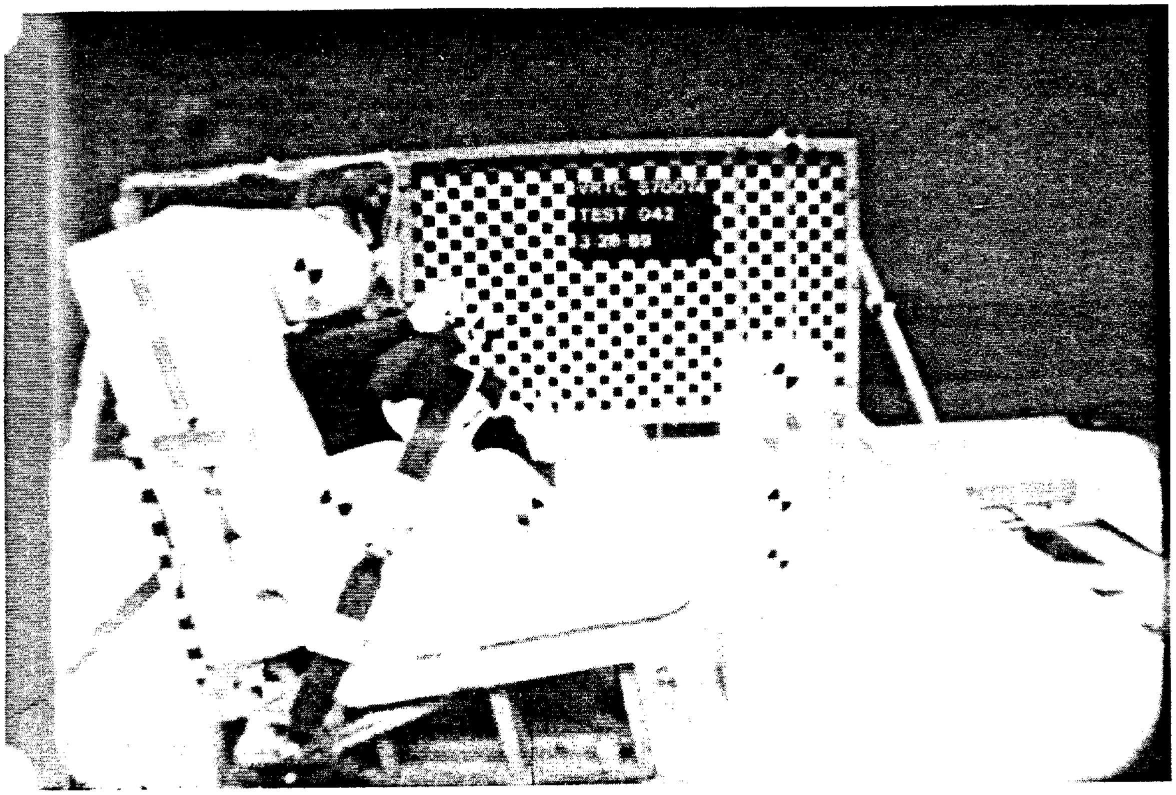


FIGURE 3.9 -- Test #944 TNO P3/4 Dummy at 0 msec

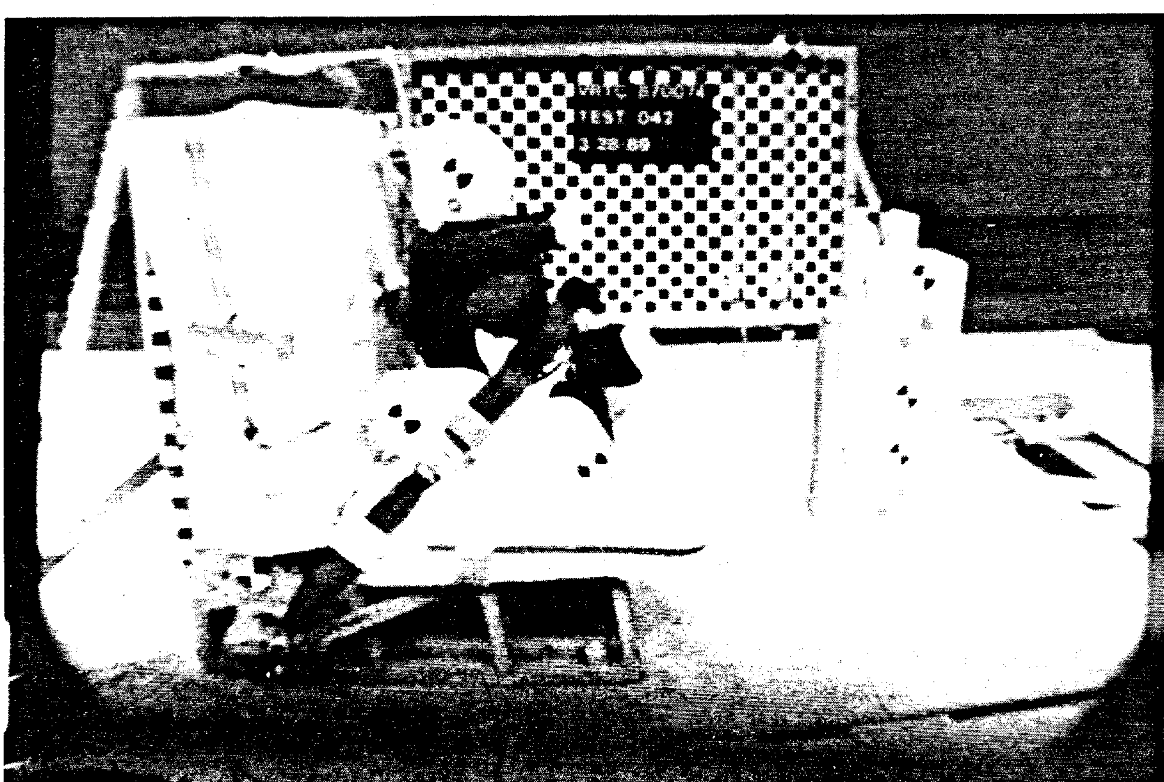


FIGURE 3.10 -- Test #944 TNO P3/4 Dummy at 50 msec

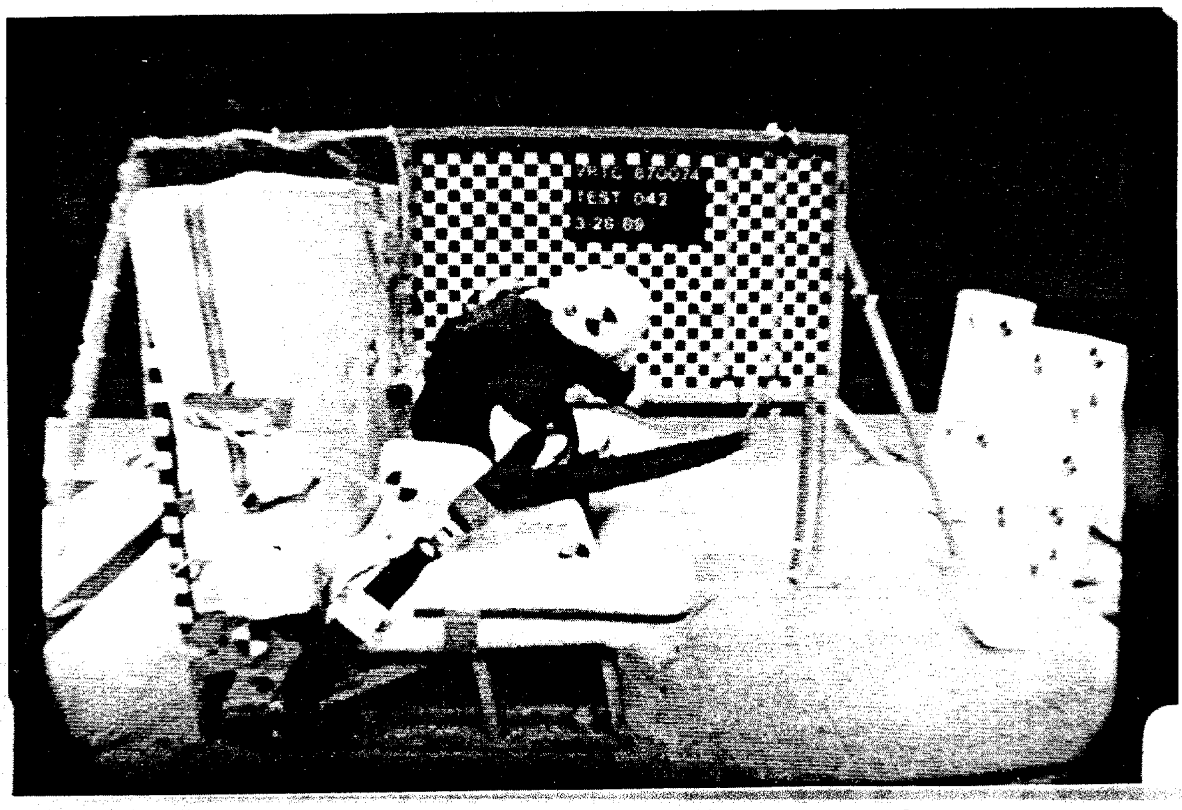


FIGURE 3.11 -- Test #944 TNO P3/4 Dummy at 79 msec

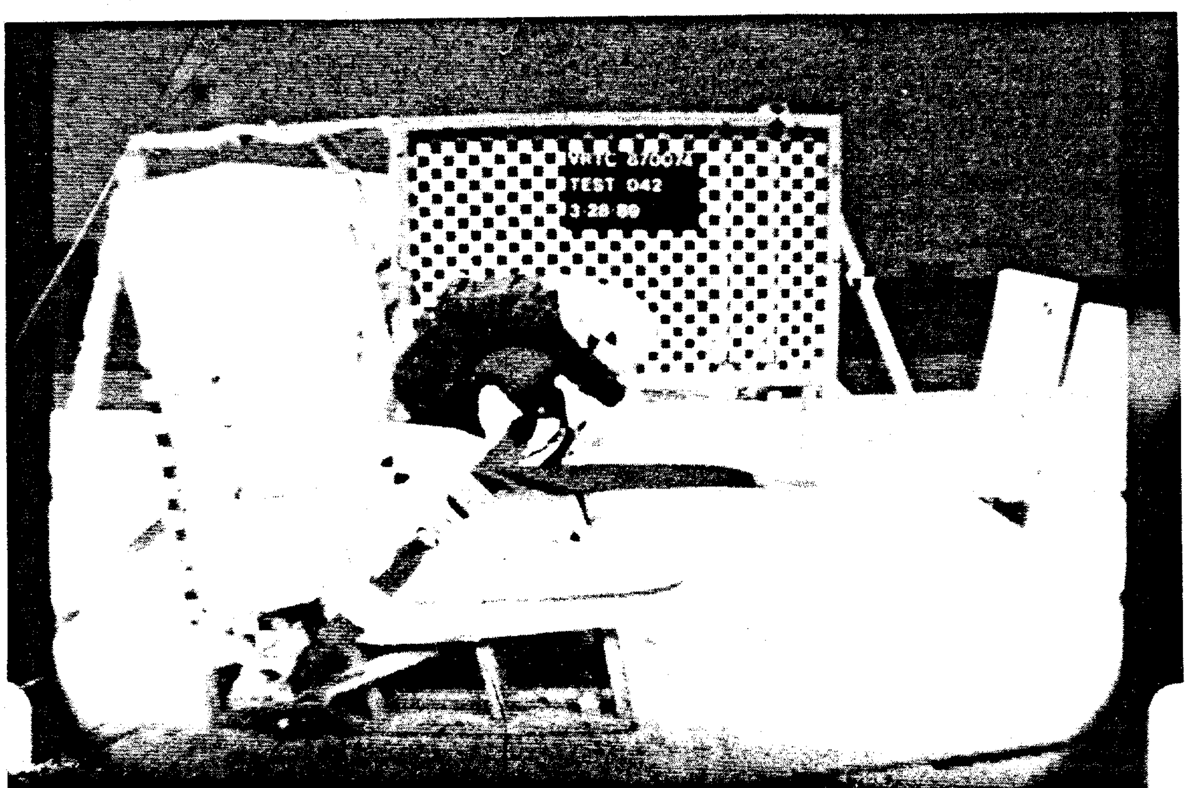


FIGURE 3.12 -- Test #944 TNO P3/4 Dummy at 92 msec

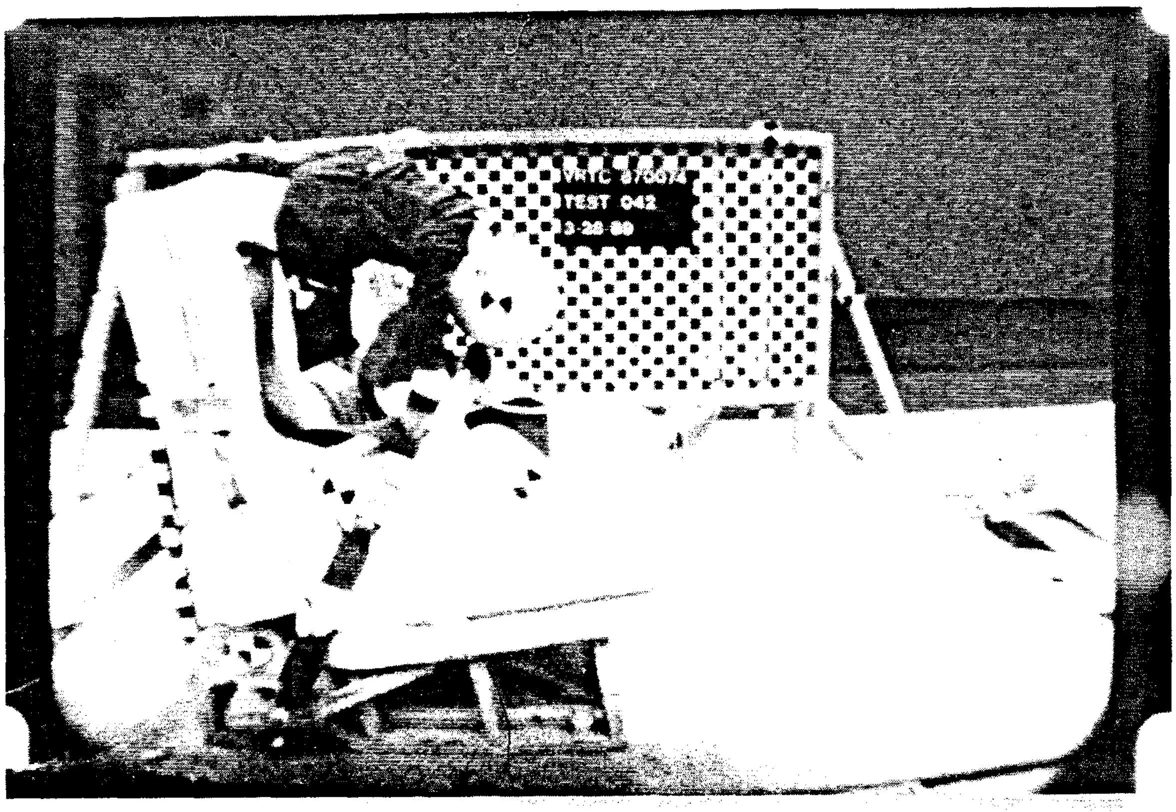


FIGURE 3.13 -- Test #944 TNO P3/4 Dummy at 359 msec

until rest (the resistive force of the brakes is taken into account the same as any other frictional loss in producing the "correct" acceleration pulse shape and magnitude).

Vehicle-to-barrier crash tests were examined for comparison with the sled tests [5,6,7 & 8]. The peak retarding acceleration experienced by the car during rebound after separating from the wall can be as much as 1 - 3 g's. This is due to front wheels locking, components dragging, etc. Based on measured rebound distances of 1.5 - 2.5 feet and an assumed rebound velocity of 3 - 5 mph, the <u>average</u> acceleration can range from approximately .15 g's to .65 g's. The approximately .36 g braking deceleration experienced on the sled is, therefore, of reasonable magnitude relative to a barrier crash. The time for the sled to come to a complete stop is, of course, much longer than in a real barrier crash. The sled's change in velocity is 30 mph compared with the car's assumed rebound velocity which is only 3 - 5 mph.

Based on a worst case combination of the above assumptions, a car rebounding from a barrier crash would come to rest not less than 230 msec after contacting the wall. In the sled tests, the P3/4 dummy was out of the booster seat between 150 and 250 msec which is within the time frame of interest in a real barrier crash. Based on this information, the occurrence of rebound ejections in these tests does not appear to be artificial or unrepresentative.

<u>Head & Torso Accelerometer Responses & Injury Criteria</u>

The head and torso accelerations of the P 3/4 child dummy were relatively small in magnitude. The HIC and peak resultant torso acceleration measurements averaged 343 and 39.4 g's with maxima of 465 and 51.1 g's.

<u>Head & Knee Excursions</u>

The head excursions averaged less than 25 inches. Knee excursions for the P 3/4 were obtainable from only two of the nine tests (#946 and #948) because the knee target was often obscured by the booster seat. However, other targets on the seats indirectly indicated that the knee typically displaced less than 22 inches from the SORL.

3.2.2 SA103

As stated before, the tests involving the SA103C were conducted at another facility as part of the NHTSA's compliance test program; the films and summary of test results were made available for this evaluation.

Ejections

The dummy was not ejected from a booster seat in any of the tests.

Head & Torso Accelerometer Responses & Injury Criteria

The head and torso dynamics criteria of FMVSS 213 were satisfied by all of the seats tested. The HIC and resultant torso acceleration measurements averaged 630 and 31.4 g's with maximum values of 792 and 38.4 g's (both occurring coincidentally in test number 5126). Standard deviations were 133 and 4.4 g's. In some of the tests, the head appeared to impact a component of the booster seat (i.e. the shield) and in other cases, the dummy's own knees.

Head & Knee Excursions

The head and knee excursion measurements also passed the FMVSS 213 criteria. Knee excursions averaged 24.6 inches with a maximum of 29.2 inches which is well below the 36 inch limit. Head excursions averaged 30.0 inches with a maximum value of 31.8 inches. Standard deviations were 1.7 and 2.3 inches. However, in four of the nine tests, the head excursion measurements were within 3% (0.8 inches) of the prescribed 32 inch limit.

3.2.3 SA106C

Ejection / Seat Failure

An ejection of the SA106C dummy occurred in test number 946. This ejection was a result of seat component separation. The shield of the Strolee Quick Click is designed to swing around from the side to contain the occupant. It is also adjustable to fit children of different sizes. The lap belt, which is routed across the shield, secures the shield in place against the child or dummy's torso/abdomen. During the loading phase in test #946, when the dummy pitched forward and over the shield, the seat bottom (booster cushion) flipped up, pivoted around and struck the dummy in the back of the head. The dummy came to rest with the lap belt still around its abdomen, laying beside the bench seat. The impact of the seat bottom with the dummy's head was insignificant with respect to the HIC.

There was one other occurrence of a seat structural failure which involved a separation of a seat's load bearing components in test number 949. The shield of the Evenflo Seven Year Booster seat, which is a two piece molded plastic construction held together by rivets, came apart during the loading phase of the test. The lap belt, which passes through the shield, and the dummy's torso loaded it in such a way that the rivets tore through the plastic nearly allowing the belt to come in direct contact with the dummy.

Head & Torso Accelerometer Responses & Injury Criteria

The HIC and resultant torso acceleration measurements averaged 494 and 31.4 g's with maxima of 796 and 44.9 g's. The standard deviations were 181 and 7.1 g's.

Head & Knee Excursion

The head and knee excursions averaged 33.8 and 29.2 inches with maxima of 40.7 and 33.6 inches. The head excursion exceeded 32 inches in seven of nine tests.

In the two seats with less than 32-inch head excursion, numbers two and four (Ford Tot Guard and Evenflo Sightseer), the height of the shield relative to the dummy's torso was the major contributor to lower head excursion levels. The dummy's upper torso forward movement was more restricted in these two seats than in the others.

3.2.4 Booster Seat Evaluation Summary

The results of the sled testing of the nine booster seats are summarized in Table 3.2. Because not all of the seats were intended to be used by children of the entire age and size range tested, the reader is referred again to Table 2.1. Because of the likelihood of misuse of seats not intended for larger or smaller children, all three sizes of dummies were tested in each of the seats.

TABLE 3.2 -- Dummy Test Results Summary

Seat	9 Month*	3 Year	6 Year
1	5+	0	1
2	5	0	0
3	5+	0	1
4	5+	0	0
5	0+	0	1,5,6,7
6	5+	0	1
7	5	0	1
8	0+	0	1,6
9	5	0	1

*These dummies are not currently specified for use in FMVSS 213.
+This dummy resides outside the recommended weight range for this booster seat.

Key: 0 - Satisfies criteria 1 through 7
1 - Head excursion > 32"
2 - Knee excursion > 36"
3 - Torso acceleration > 60 g's
4 - HIC > 1000
5 - Ejection
6 - Seat component separation
7 - Seat changed adjustment

It is noted in Table 3.2 that only two of the seats, numbers five and eight (Strolee Quick Click and Evenflo Booster) did not result in the ejection of the nine-month old dummy.

All of the seats' tests were successful with the three-year-old dummy, which is required for FMVSS 213.

Seven of the seats, all except numbers two and four (Ford Tot Guard and Evenflo Sightseer), when tested with the six-year-old dummy would not satisfy the requirements specified for the three-year-old dummy in FMVSS 213. Two seats, numbers five and eight (Strolee Quick Click and Evenflo Booster), experienced component separation. Although these two seats were recommended by the manufacturers for occupants up to 60 pounds, both experienced structural failure with a dummy weighing only 46 pounds.

3.3 Modified and Standard Dummy Comparison

The second objective of this project was to compare the performance of modified dummies with unmodified ("standard") dummies. The modified dummies were equipped with instrumented, penetration sensing abdominal inserts. The modified abdominal insert replaced the standard uninstrumented foam filled vinyl bladder. The purpose of this comparison is to assess the affect of the abdominal modifications on overall dummy performance, not to determine the suitability of the abdominal sensor. Measurements from the abdominal sensors are not presented in this report.

Only the tests involving the unmodified SA106C dummy were performed at TRC. All of the tests involving the SA103C (modified and unmodified) and the modified SA106C dummies were performed at the Calspan Corporation's sled facility at Buffalo, New York. The tests involving the standard SA103C dummy were part of a series of compliance tests performed for the NHTSA and adhered to the specified FMVSS 213 procedures.

3.3.1 Dummy Modifications

The three- and six-year-old dummies used at Calspan were both similarly modified with a device developed at the University of Michigan Transportation Research Institute (UMTRI). The device was designed to measure intrusion into the abdominal cavity of a child dummy [9].

The device is a fluid filled tube wrapped several times around the lumbar spine in the abdominal cavity of the dummy. The tube is connected to an air filled tube which is instrumented with a pressure transducer. When an external force is applied (for example, by a belt or booster seat shield) to the abdomen, squeezing the coils of tubing, a change in pressure can be measured and recorded. A schematic of the device and its location in a dummy is shown in Figure 3.14. A more detailed description of the device and its use in these tests can be found in References 3 and 9.

An important feature of the abdominal insert is the cylinder which resides posterior to the thoracic spine. This cylinder affects the dummy's seated posture because it prevents the dummy from sitting normally, with its back flat against the seat.

3.3.2 Test Results

Tables 3.3 and 3.4 present the data from the comparable sets of tests for each dummy. The data for the unmodified dummies also appear in Table 3.1. There were eight comparable tests for the SA103C and seven for the SA106C. Some tests involving the modified dummy were repeated because of lost data channels. To account for the additional data, repeated tests were averaged and used as a single data point.

Figures 3.15 through 3.22 present the data from Tables 3.3 and 3.4 in bar graph form. Illustrated in these bar graphs are the average magnitude plus or minus one standard deviation of the responses for both the standard and modified dummies. Individual results are presented in bar graphs in Appendix C.

TABLE 3.3 -- SA103C Dummy Comparison Results

Test Number Std	Test Number Mod	Booster Seat	Booster Seat Code	Peak Head Resultant Acceleration (g)* Std	Peak Head Resultant Acceleration (g)* Mod	HIC Std	HIC Mod	Peak Head Excursion (in) Std	Peak Head Excursion (in) Mod	Peak Torso Acceleration (g)* Std	Peak Torso Acceleration (g)* Mod	Peak Knee Excursion (in) Std	Peak Knee Excursion (in) Mod	Ejection Std	Ejection Mod
---	4577	Gerry Voyager	GV	---	70	---	774	---	31.8	---	35.0	---	30.4		
5127	4578	Gerry Voyager	GV	---	60	742	530	31.6	32.6	36.2	32.1	29.2	30.6		
---	4514	Ford Tot Guard	FTG	---	52	---	648	---	34.2	---	34.2	---	26.6		
5126	4514	Ford Tot Guard	FTG	---	65	792	754	31.7	33.7	38.4	36.9	27.5	25.6		
5125	4573	Pride-Trimble Click N' Go	PTCNG	---	72	515	824	31.2	33.2	27.2	29.8	22.3	25.3		Y
5122	4577	Strolee Quick Click	SQC	---	50	462	469	31.8	32.4	26.2	24.6	24.6	26.5		
5131	4574	Cosco Explorer I	CE I	---	55	---	796	---	---	---	30.3	---	---		
---	4578	Cosco Explorer I	CE I	---	61	769	785	28.5	29.2	33.1	30.8	23.6	26.8		
5121	4576	Kolcraft Tot-Rider Quickstep	KTRQS	---	45	467	318	29.8	33.1	26.7	26.3	22.3	26.0		Y
5130	4575	Evenflo 7 Year Booster	EB	---	59	736	459	28.3	30.0	31.3	37.7	24.5	33.0		
5129	4573	Century Commander	CC	---	63	619	666	29.8	31.0	29.4	29.4	23.3	24.6		
			AVERAGE		58.8	638	610	30.3	31.9	31.1	30.9	24.7	27.4	0%	25%
			STANDARD DEV.		7.9	140	166	1.4	1.6	4.5	4.2	2.5	2.7		

*Peak pulse duration of 3 msec

TABLE 3.4 -- SA106C Dummy Comparison Results

Test Number Std	Test Number Mod	Booster Seat	Booster Seat Code	Peak Head Resultant Acceleration (g)* Std	Peak Head Resultant Acceleration (g)* Mod	HIC Std	HIC Mod	Peak Head Excursion (in) Std	Peak Head Excursion (in) Mod	Peak Torso Acceleration (g)* Std	Peak Torso Acceleration (g)* Mod	Peak Knee Excursion (in) Std	Peak Knee Excursion (in) Mod	Ejection Std	Ejection Mod
---	4524	Ford Tot Guard	FTG	---	53	---	545	---	33.1	---	34.9	---	30.4		
943	4524	Ford Tot Guard	FTG	57.6	56	530	583	27.0	33.6	35.8	39.2	34.2	29.0		
944	4579	Pride-Trimble Click N' Go	PTCNG	51.9	62	435	846	33.8	35.3	26.5	29.0	27.7	27.5		
946	4586	Strolee Quick Click	SQC	46.3	51	365	516	40.7	35.2	25.5	24.6	30.0	28.6	Y	
947	4580	Cosco Explorer I	CE I	64.1	55	796	501	33.1	32.3	35.4	30.3	26.5	28.5		
948	4585	Kolcraft Tot-Rider Quickstep	KTRQS	41.0	38	291	263	33.6	34.5	22.2	21.5	28.6	29.2		
950	4582	Century Commander	CC	64.0	53	674	428	34.0	32.8	29.5	27.1	26.9	27.5		
949	4583	Evenflo 7 Year Booster	EB	44.4	---	272	---	36.7	32.0	27.1	32.1	28.5	36.0		
			AVERAGE	52.8	52	480	520	34.1	33.6	28.9	28.8	28.9	29.6	12%	0%
			STANDARD DEV.	9.4	7.8	198	189	4.1	1.4	5.1	5.1	2.6	2.9		

*Peak pulse duration of 3 msec

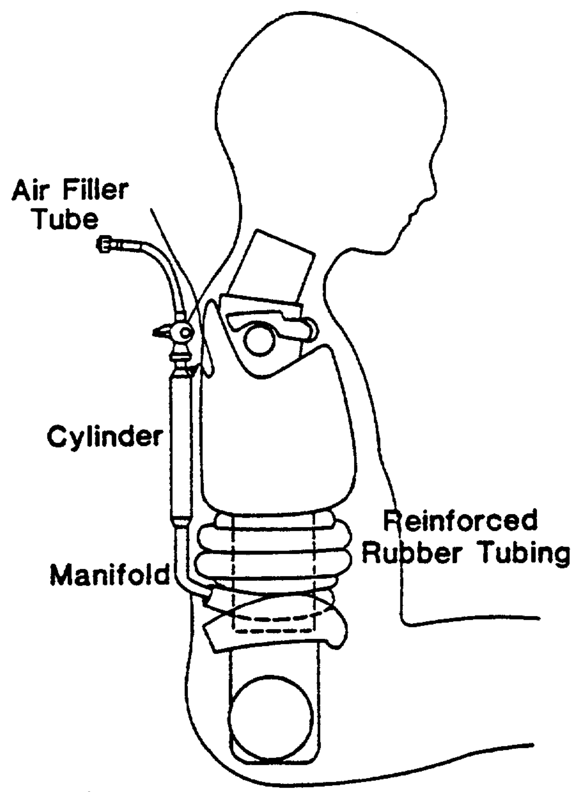


FIGURE 3.14 -- UMTRI Abdominal Intrusion Sensor

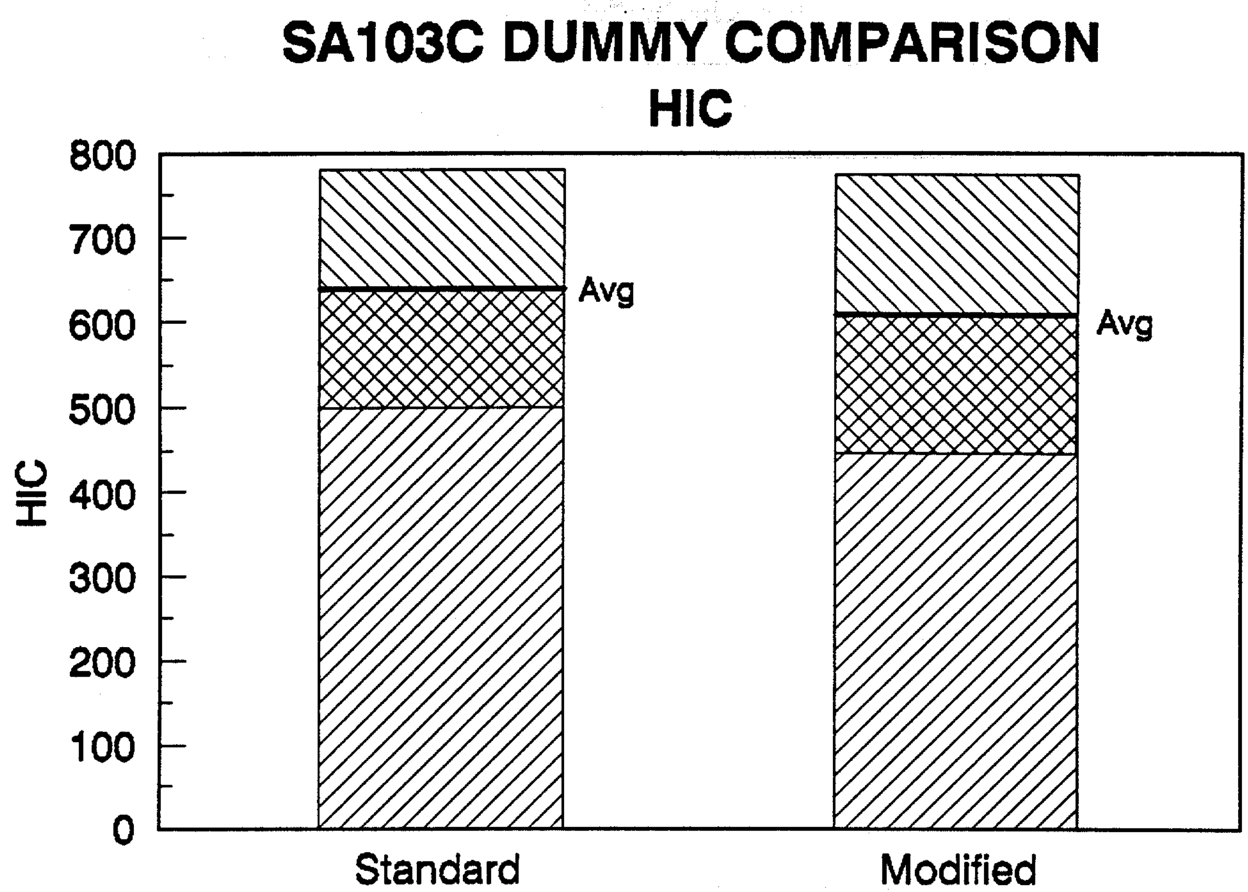


FIGURE 3.15 — SA103C Dummy Comparison: Average HIC

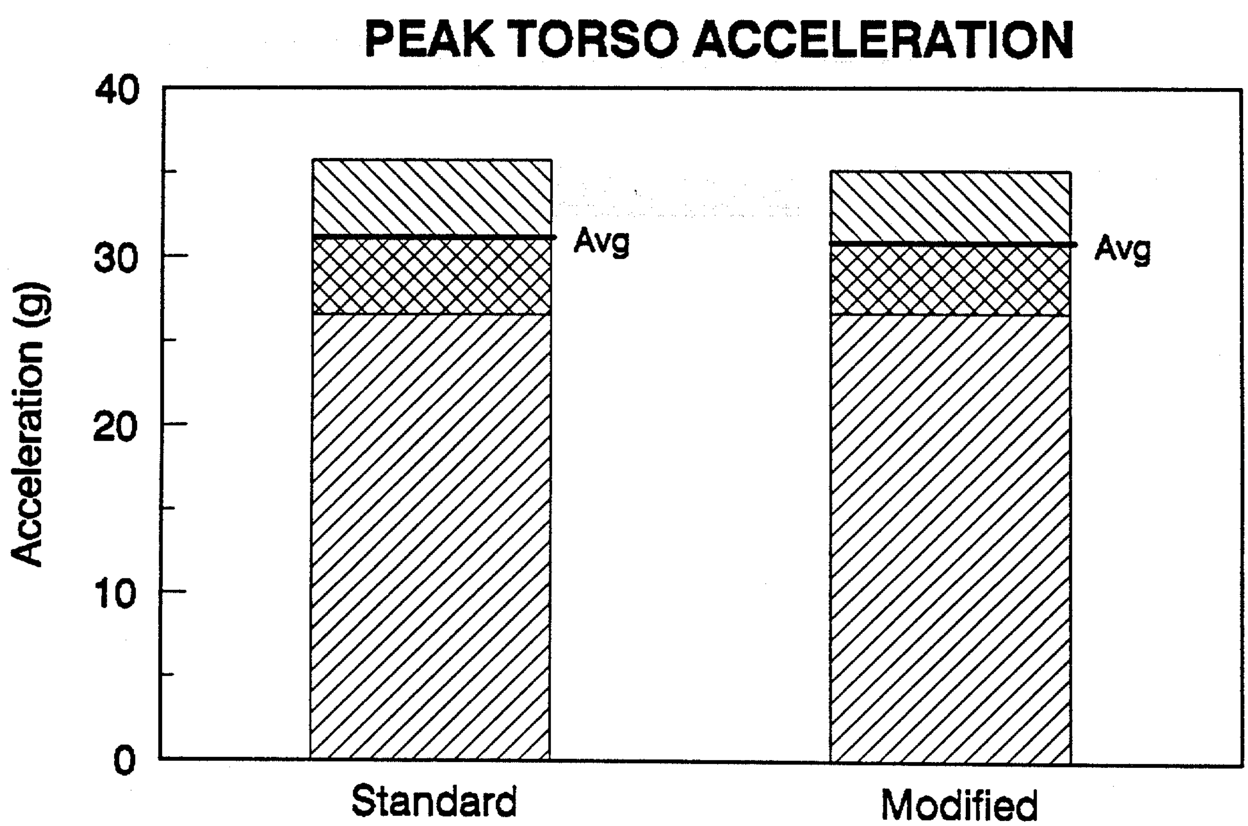


FIGURE 3.16 — SA103C Dummy Comparison: Average Torso Acceleration

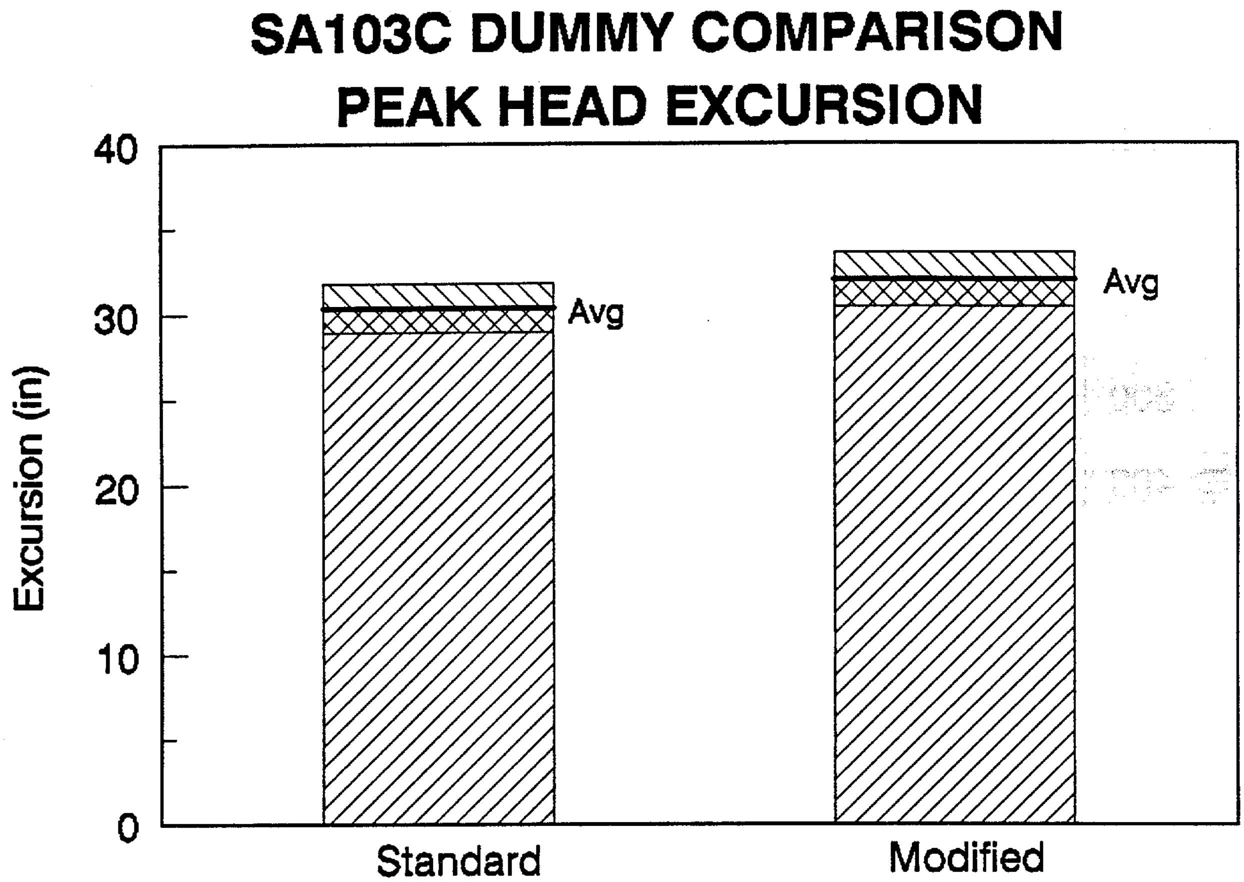


FIGURE 3.17 -- SA103C Dummy Comparison: Average Head Excursion

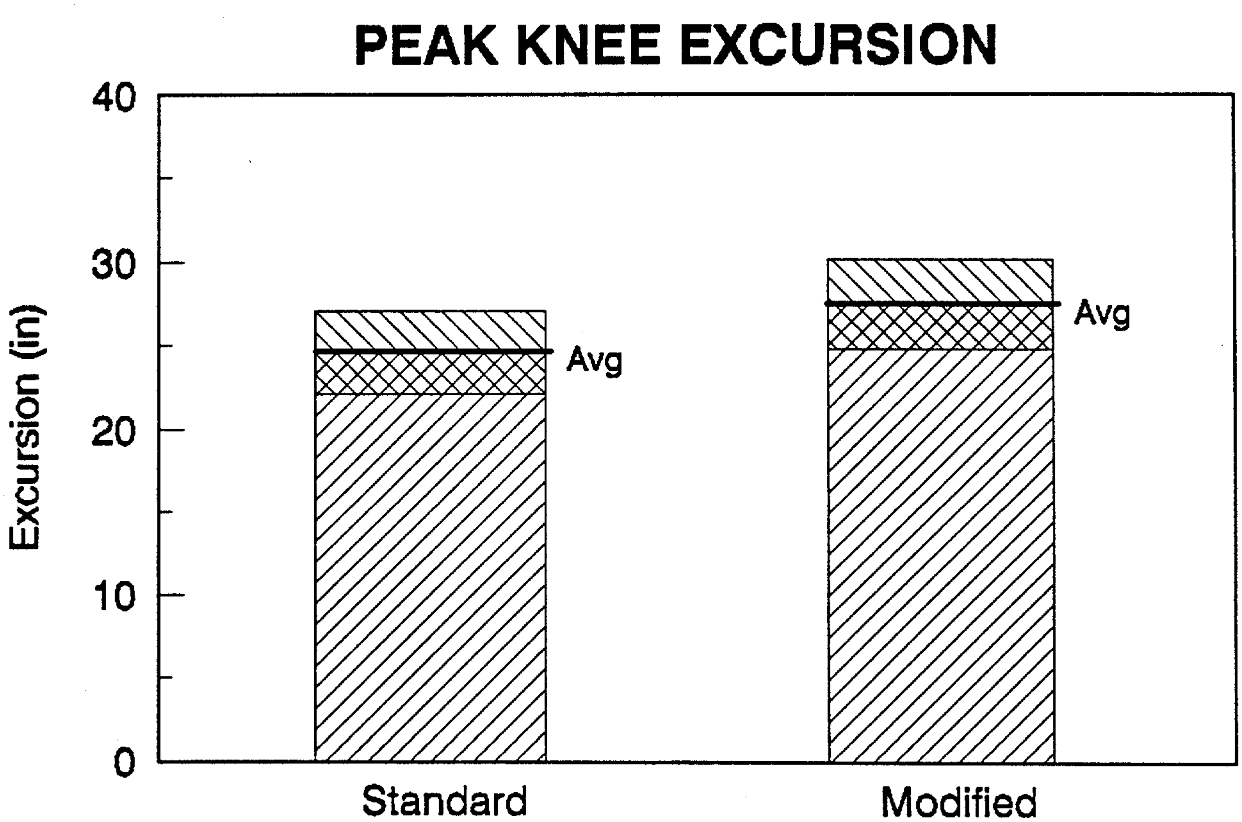


FIGURE 3.18 -- SA103C Dummy Comparison: Average Knee Excursion

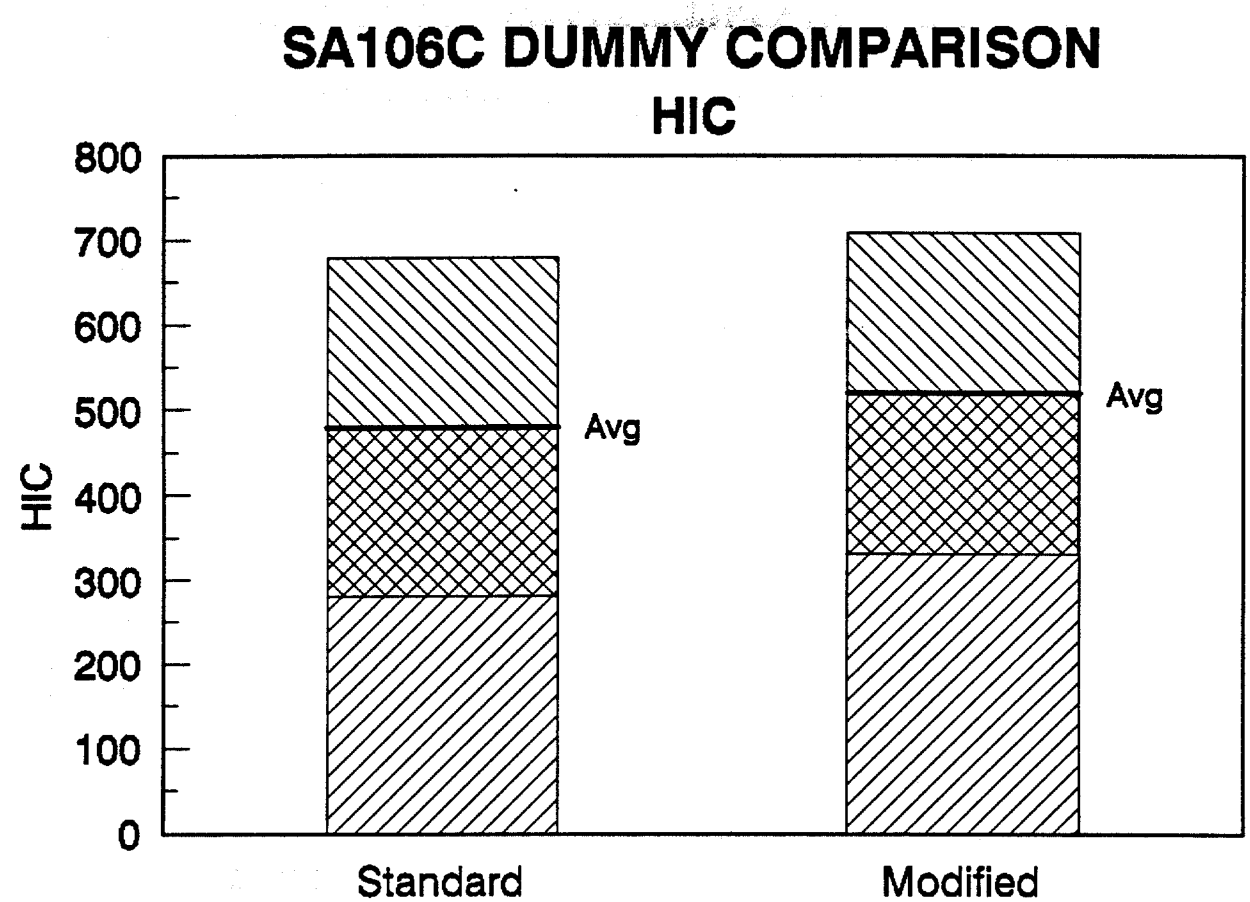


FIGURE 3.19 — SA106C Dummy Comparison: Average HIC

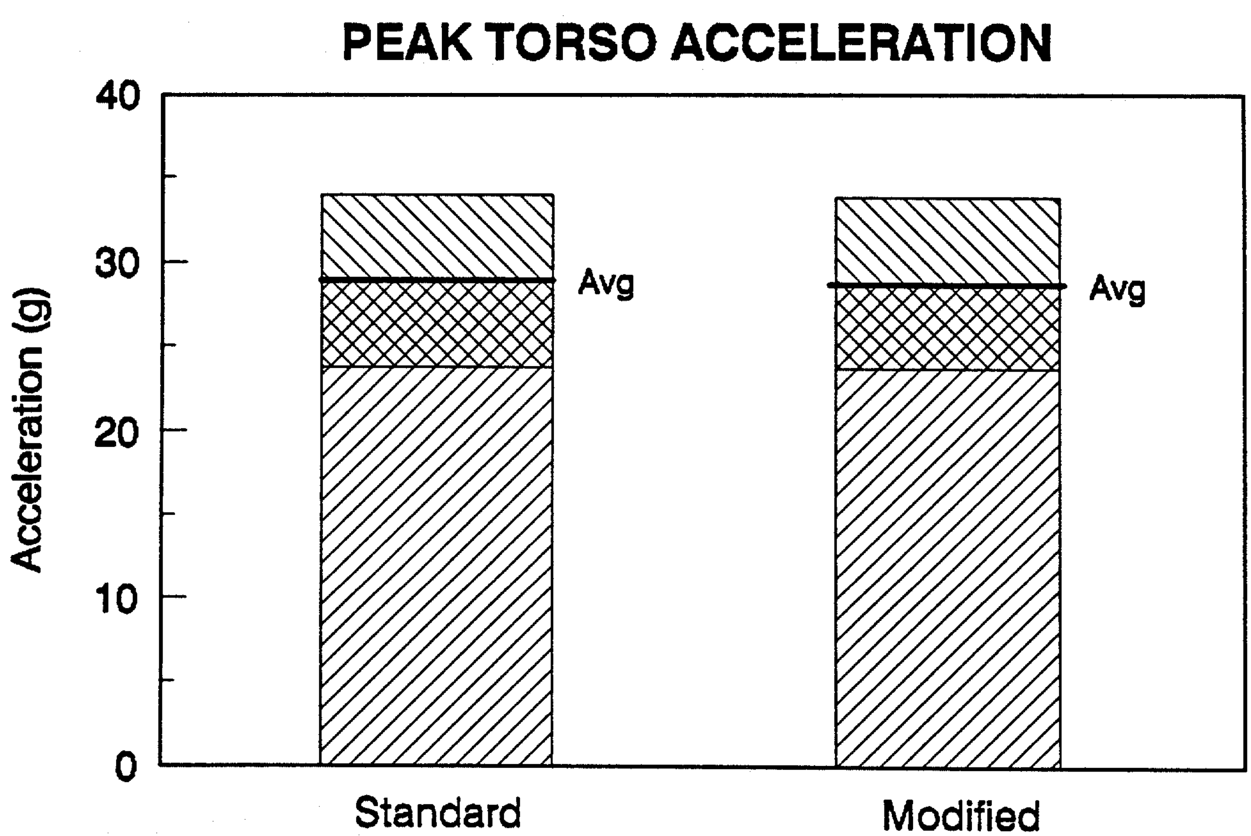


FIGURE 3.20 — SA106C Dummy Comparison: Average Torso Acceleration

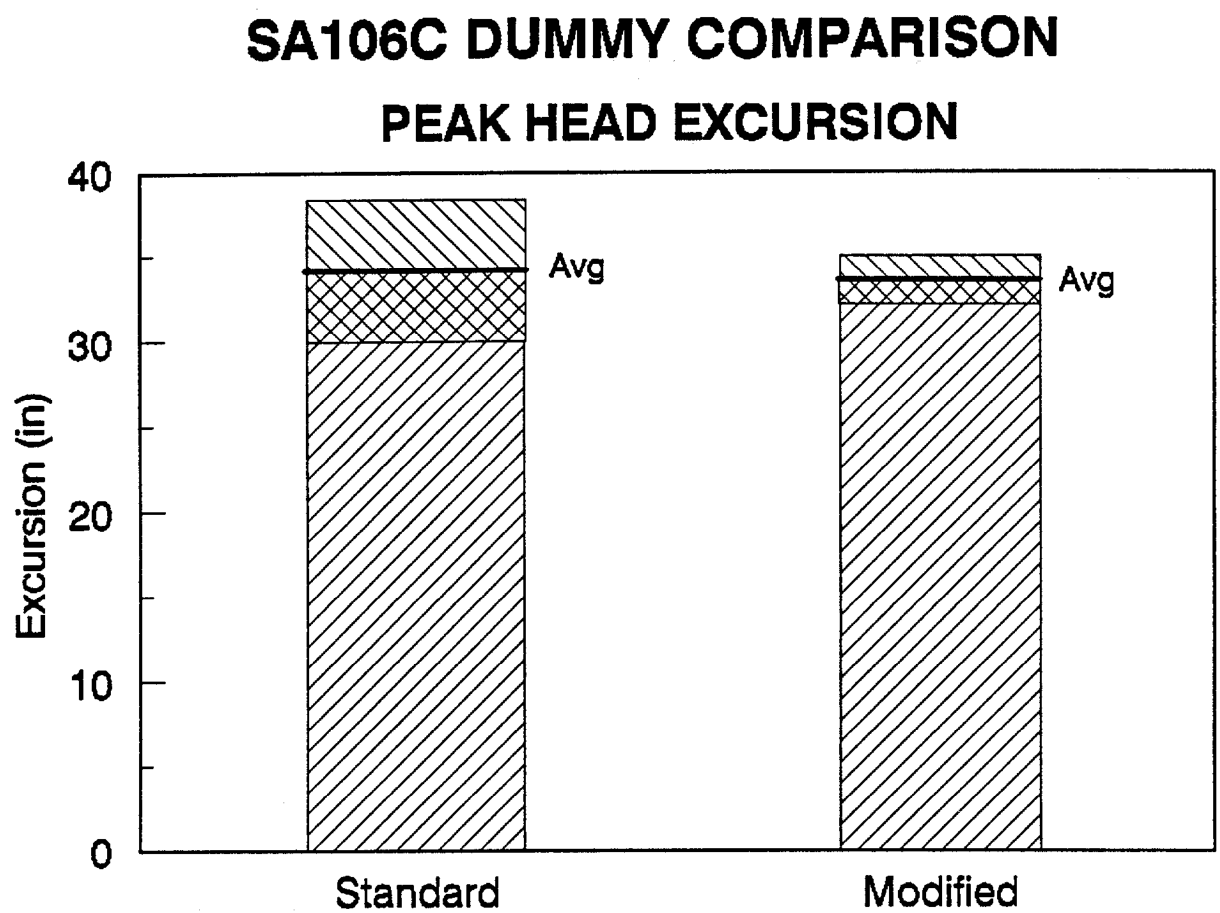


FIGURE 3.21 — SA106C Dummy Comparison: Average Head Excursion

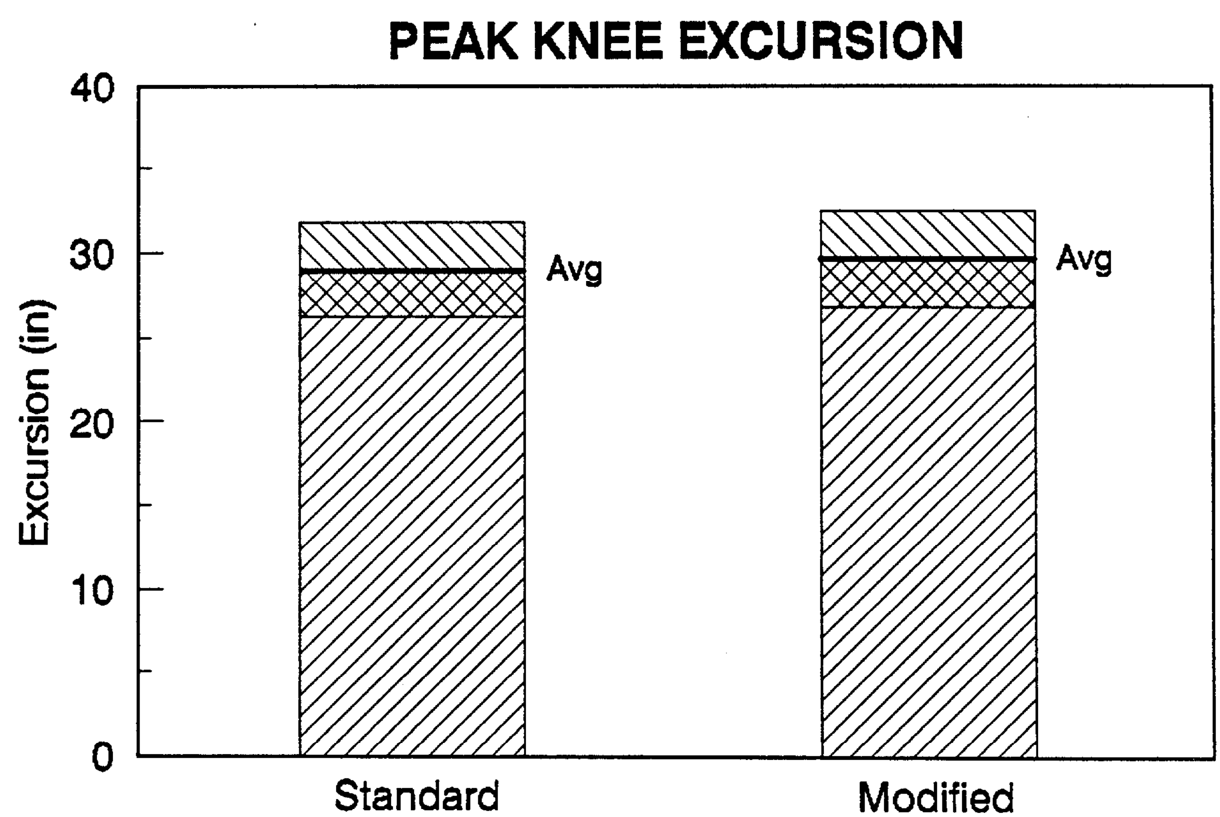


FIGURE 3.22 — SA103C Dummy Comparison: Average Knee Excursion

3.3.3 SA103C

The modified dummy was ejected twice, in tests 4573 and 4576; the standard dummy was not ejected at all.

The head acceleration data for the standard dummy were not available because it is not reported in compliance test reports. The head acceleration data from the modified dummy are listed in Table 3.3 but are not used in the analysis.

Generally, the modified dummy displayed slightly lower HICs and torso accelerations (Figures 3.15 & 3.16) and higher head and knee excursions. The differences in mean HIC values and torso accelerations are not statistically significant because they are within the variation represented by ± 1 standard deviation.

Although the differences in head excursion levels appear only marginally statistically significant, they are important if one were trying to stay within the 32 inch limit; the modified dummy exceeded this in five of the seats (six tests).

Because all of the tests were conducted at the same facility, laboratory nonreproducibility is not as likely to be a significant factor in these results. Possible explanations for the altered response of the modified dummy are:

1. The abdominal sensor's air cylinder, which is positioned posterior to the dummy's thoracic spine, affected the initial seated posture and, ultimately, the kinematics.

2. The abdominal sensor's tubing may have affected the interaction of the dummy with the booster seat shield possibly because of different abdominal stiffness and geometry, or altered lumbar flexion response.

3.3.4 SA106C

The data comparing the modified and standard dummies' responses are in Table 3.4. Figures 3.19 through 3.22 show these data in bar graph form.

The standard dummy was ejected once; the modified dummy not ejected in any tests. The single ejection of the standard dummy was related to the inability of the seat's load bearing structures to remain in contact with one another as described in section 3.2.3.

It is evident from examination of the four figures that there were no significant response differences. Both dummies exceeded 32" head excursion in six of seven seats, although the seats in which each dummy exceeded 32" were not the same. The head excursion averages for both dummies were very similar; however, the standard deviations were remarkably different. This can be explained by examining two tests with the standard dummy, numbers 943 and 946, where the head excursions were 27 and 40.7 inches. Without including these tests in the calculation, the average remains nearly the same (within .1 inches) but the standard deviation decreases to 1.4 inches, the same as that of the modified dummy. Seat structural failure is responsible for the difference in test 946. In test 943, the seat cushion provided with the safety seat was not used with the standard dummy, but was apparently used with the modified dummy. The greater shield height relative to the standard dummy's torso would explain the lesser head excursion.

From Figure 3.19, it is observed that the HIC responses of both dummies varied considerably. Films were available for the standard dummy tests but not the modified dummy tests. The films of the standard dummy were reviewed to determine if the head had struck the seat or legs in some tests but not in others. This was proven untrue; the differences were apparently caused by variations in the head's whipping motion observed in different seats.

4.0 SUMMARY/CONCLUSIONS

Sled tests were done in which dummies representing nine-month, three-year and six-year-old children were tested in nine different automotive booster safety seats. These data were examined to determine the relative crash protection offered by booster seats as a group to the range of occupants represented by the three dummies. The dynamic tests, which were conducted on a HYGE sled, were similar to the FMVSS 213 compliance test used to certify child safety seats.

Head and torso resultant accelerations as well as head and knee excursion data were collected from each of the dummies and compared to the current FMVSS 213 criteria established for the three-year-old SA103C dummy. The following conclusions are offered about booster seat performance:

1) Based on the ejection rate in these tests, forward facing booster seats with abdominal shields, in general, are not appropriate for a nine-month old child (a child weighing 20 pounds and standing 18 inches) or smaller.

    The dummy was ejected from seven of the nine seats tested. Two of the seven seats were recommended by the manufacturer for a child of that size, one recommended 25 pounds and the rest were for children weighing at least 30 pounds. The anthropometry of the nine-month old child dummy is clearly incompatible with this type of restraint.

2) All nine booster seats passed the requirements of FMVSS 213 with the standard three-year-old dummy.

3) For the six-year-old dummy, seven of the seats had head excursions greater than 32 inches. Additionally, there were two structural failures with the 46-pound six-year-old dummy. Many of the booster seat manufacturers recommend use of their seats with children weighing up to 60 pounds and some as much as 70 pounds.

The second objective of this report is to compare the results of sled tests conducted with modified and unmodified versions SA103C and SA106C dummies. The modifications consisted of replacement of the standard abdomens with instrumented abdomens designed and built at UMTRI. The purpose of the comparisons was to determine whether the new abdomen affected the performance of either dummy. The following conclusions were drawn from this comparison.

4) The performance of the modified three-year-old dummy was different from the standard three-year-old dummy. These differences were important, but not statistically significant.

The modified three-year-old exceeded 32 inches of head excursion in five of eight seats tested, compared with the standard dummy which had less than 32 inches of head excursion in all comparable tests. The average HIC and torso accelerations were not significantly affected. The average maximum knee excursion increased by more than 10% but remained almost nine inches below 36 inches. The modified dummy was ejected twice; the standard dummy was not ejected at all.

5) The performance of the modified six-year-old dummy was statistically similar to the unmodified six-year-old dummy.

Both dummies' head excursion exceeded 32 inches in six of seven seats. The modified dummy's average HIC was more than 8% greater but both dummies average HIC's had fairly high standard deviations. The average torso acceleration and average maximum knee excursion were not significantly affected. The standard dummy was ejected once; the modified dummy was not ejected at all.

5.0 REFERENCES

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3. Naab, Kenneth, "Performance Repeatability of the SA106C Six-Year-Old Child Test Dummies," 29th Stapp Car Crash Conference Proceedings, Pubication No. P-167, pp 129-145, 1985.

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8. U.S. Department of Transportation National Highway Traffic Safety Administration, "Vehicle Barrier Impact Testing with Hybrid III Dummies in a 1987 Chrysler 2-Door Coupe," Test Report No. DOT HS 807 242, 1987.

9. Melvin, John W., Weber, Kathleen, "Abdominal Intrusion Sensor for Evaluating Child Restraint Systems," 1986 SAE International Congress and Exposition Session: <u>Passenger Comfort Convenience and Safety: Test Tools and Procedures</u>, Publication No. P-174, pp 249-256, 1986.

APPENDIX A

Dummy Calibration Results

P¾ LUMBAR TESTS:

NOV 30 TEST No. 1:

DUMMY AS RECIEVED FROM VRTC.
LUMBAR SPRING COMPRESSED TO 9/16" LENGTH.

PEAK PULL FORCE AT 40 DEG - 27 lbs
REBOUND AFTER 3 MINUTES - < ½ DEG FROM ZERO

NOV 30 TEST No 2:

LUMBAR SPRING RELEASED AND FREE LENGTH MEASURED AS ¾". LUMBAR SPRING THEN COMPRESSED TO ½" LENGTH.

PEAK PULL FORCE AT 40 DEG - 25 lbs.
REBOUND AFTER 3 MINUTES - < 1 DEG FROM ZERO

TNO P3/4 CALIBRATION RESULTS

09/20/89

	PEAK g's (50-58)	LATERAL g's ($\leq$ 7g)	UNIMODAL (5$\leq$ t $\leq$ 6msec) duration
HEAD			
Pre test	62.6g	3.5g	no
Post test	58.8g	5.6g	no
CHEST	(65-75g)	($\leq$ 7g)	(5$\leq$ t $\leq$ 6 msec) duration
Pre test	80.9g	4.7g	yes
Post test	82.1g	4g	yes*

* questionable

TNO P3/4 CALIBRATION RESULTS

09/20/89

	PEAK g's (50-58)	LATERAL g's (≤ 7g)	UNIMODAL (5≤ t ≤ 6msec) duration
HEAD			
Pre test	62.6g	3.5g	no
Post test	58.8g	5.6g	no
CHEST	(65-75g)	(≤ 7g)	(5≤ t ≤ 6 msec) duration
Pre test	80.9g	4.7g	yes
Post test	82.1g	4g	yes*

* questionable

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HEAD IMPACT TEST

PART 572 - 6 YR. OLD 22-Mar-89

TEMPERATURE 72 F RELATIVE HUMIDITY 25 %

VRTC HD10204 6 YR SN H102 HEAD IMPT CAL04

TEST PARAMETER	Recommended SPECIFICATION	TEST RESULTS
PENDULUM VELOCITY	6.9 - 7.1 fps	7.08 FT/SEC
PEAK RESULTANT ACCELERATION	140 - 180 g	211.40 G
TIME ABOVE 50 G LEVEL	2 - 3 msec	1.15 MSEC
PEAK LATERAL ACCELERATION	≤ 7 g	6.05 G
IS ACCELERATION CURVE UNIMODAL?	Yes	YES

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HEAD IMPACT TEST

PART 572 - 6 YR. OLD 31-Mar-89

TEMPERATURE 71 F
VRTC HD10205

RELATIVE HUMIDITY 40 %
6 YR SN H102 HEAD IMPT CAL05

TEST PARAMETER	Recommended SPECIFICATION	TEST RESULTS
PENDULUM VELOCITY	6.9 - 7.1 fps	7.05 FT/SEC
PEAK RESULTANT ACCELERATION	140 - 180 g	208.48 G
TIME ABOVE 50 G LEVEL	2 - 3 msec	1.16 MSEC
PEAK LATERAL ACCELERATION	≤ 7 g	-5.55 G
IS ACCELERATION CURVE UNIMODAL?	yes	YES

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CHEST IMPACT TEST

PART 572 - 6 YR. OLD 22-Mar-89

TEMPERATURE 72 F RELATIVE HUMIDITY 25 %
VRTC TH10204 6 YR SN 4102 CHEST IMPT CAL04

TEST PARAMETER	Recommended SPECIFICATION	TEST RESULTS
PENDULUM VELOCITY	19.7 - 20.3 fps	20.25 FT/SEC
PEAK RESULTANT ACCELERATION	36 - 90 g	72.65 G
TIME ABOVE 30 G LEVEL	2.5-4.0 msec	5.10 MSEC
PEAK LATERAL ACCELERATION	≤ 5g	-4.28 G
IS ACCELERATION CURVE UNIMODAL?	yes	YES

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CHEST IMPACT TEST

PART 572 - 6 YR. OLD 31-Mar-89

TEMPERATURE 71 F
VRTC TH10205

RELATIVE HUMIDITY 40 %
6 YR SN H102 CHEST IMPT CAL05

TEST PARAMETER	Recommended SPECIFICATION	TEST RESULTS
PENDULUM VELOCITY	19.7 - 20.3 fps	19.80 FT/SEC
PEAK RESULTANT ACCELERATION	36 - 90 g	80.33 G
TIME ABOVE 30 G LEVEL	2.5 - 4.0 msec	5.26 MSEC
PEAK LATERAL ACCELERATION	≤ 5 g	5.73 G
IS ACCELERATION CURVE UNIMODAL?	yes	YES

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NECK PENDULUM TEST

PART 572 - 6 YR. OLD 22-Mar-89

TEMPERATURE 71.00 F RELATIVE HUMIDITY 27.00 %

VRTC HN10204 6 YR SN H102 HEAD/NECK CAL04

TEST PARAMETER	SPECIFICATION	TEST RESULTS
PENDULUM VELOCITY	16 TO 18 FT/SEC	16.90 FT/SEC
PENDULUM DECELERATION:		
T1 - T2: 5 - 20 G	4 MSEC MAX	2.58 MSEC
T2 - T3: 20 - 20 G	18 - 22 MSEC	18.82 MSEC
T3 - T4: 20 - 5 G	6 MSEC MAX	3.47 MSEC
AVG G LEVEL T2 - T3	20 - 34 G	24.54 G
MAXIMUM ROTATION ANGLE	76° - 92°	77.02 DEG
PEAK HEAD RESULTANT ACCEL	≤ 30g	24.80 G

TEST PARAMETER	SPECIFICATION		TEST RESULTS	
ROTATION ANGLE (DEGREES)	TIME (MSEC)	CHORDAL DISP (IN)	TIME (MSEC)	CHORDAL DISP (IN)
0	-2 → +2	-.8 → +.8	1.38	0.00
30	19.2 → 26.8	1.7 → 3.3	29.45	2.64
60	32.9 → 43.0	3.7 → 5.3	44.97	4.58
MAX	60.6 → 75.4	5.2 → 6.8	69.75	5.82
60	90.0 → 110.0	3.7 → 5.3	99.24	4.54
30	109.3 → 132.7	1.7 → 3.3	121.03	2.37
0	126.8 → 153.2	-.8 → +.8	141.29	0.06

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NECK PENDULUM TEST

PART 572 - 6 YR. OLD 31-Mar-89

TEMPERATURE 72.00 F RELATIVE HUMIDITY 39.00 %
VRTC HN10205 6 YR SN H102 HEAD/NECK CAL05

TEST PARAMETER	SPECIFICATION	TEST RESULTS
PENDULUM VELOCITY	16 TO 18 FT/SEC	16.90 FT/SEC
PENDULUM DECELERATION:		
T1 - T2: 5 - 20 G	4 MSEC MAX	2.63 MSEC
T2 - T3: 20 - 20 G	18 - 22 MSEC	19.06 MSEC
T3 - T4: 20 - 5 G	6 MSEC MAX	4.43 MSEC
AVG G LEVEL T2 - T3	20 - 34 G	23.60 G
MAXIMUM ROTATION ANGLE	76°-92°	80.81 DEG
PEAK HEAD RESULTANT ACCEL	≤ 30g	23.96 G

TEST PARAMETER	SPECIFICATION		TEST RESULTS	
ROTATION ANGLE (DEGREES)	TIME (MSEC)	CHORDAL DISP (IN)	TIME (MSEC)	CHORDAL DISP (IN)
0	-2 → +2	-.8 → +.8	1.38	0.00
30	19.2 → 26.8	1.7 → 3.3	29.82	2.69
60	32.9 → 43.0	3.7 → 5.3	44.61	4.58
MAX	60.6 → 75.4	5.2 → 6.8	73.63	6.17
60	90.0 → 110.0	3.7 → 5.3	104.66	4.60
30	109.3 → 132.7	1.7 → 3.3	125.31	2.41
0	126.8 → 153.2	-.8 → +.8	144.28	0.13

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LUMBAR FLEXION TEST

PART 572 - 6 YR. OLD 22-MAR-89

TEMPERATURE 72.00 F
VRTC LF10204

RELATIVE HUMIDITY 27.00 %
6 YR SN H102 LUMBAR/FLEX CAL04

DEFLECTION	SPECIFICATION	TEST RESULTS
Force @ 40 DEG Rotation, lbs	42 - 54	39.00 LB
NET RETURN ANGLE AT 3 MIN POST TEST	$\leq 5^{\circ}$	3.39 DEG

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LUMBAR FLEXION TEST

PART 572 - 6 YR. OLD 31-MAR-89

TEMPERATURE 72.00 F
VRTC LF10205

RELATIVE HUMIDITY 39.00 %
6 YR SN H102 LUMBAR/FLEX CAL05

DEFLECTION	SPECIFICATION	TEST RESULTS
Force @ 40 DEG Rotation, lbs	42-54	41.00 LB
NET RETURN ANGLE AT 3 MIN POST TEST	≤ 5°	2.60 DEG

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S 572.51 Head.

(a) The head consists of the assembly shown in drawing LP 1049/A, and conforms to each of the applicable drawings listed under LP 1049/0 through 54.

(b) When the head of a completely assembled dummy is impacted in accordance with paragraph (c) of this section by a test probe conforming to S 572.21 (a)

at 7 fps., the head resultant acceleration measured at the location of the accelerometer mounted in the headform in accordance with S 572.55 (b) shall not be less than 50g and not more than 58g. The recorded acceleration-time curve for this test shall be unimodal at the 20g level and shall lie at, or above that level for an interval not less than 5 and not more than 6.5 milliseconds. The lateral acceleration vector shall not exceed 7.0g.

(c) Test procedure. (1) Seat the dummy on a seating surface having a back support as specified in S 572.55 (g) and orient the dummy in accordance with S 572.55 (g) and adjust the joints of the limbs at any setting between 1 g and 2 g, which just supports the limb's weight when the limbs are extended horizontally forward.

(2) Adjust the test probe so that its longitudinal centerline is at the forehead at the point of orthogonal intersection of the head midsagittal plan and the transverse plane which is perpendicular to the "Z" axis of the head (longitudinal centerline of the skull) and is located ___ $\pm$ 0.1 inches below the top of the head measured along the head's "Z" axis.

(3) Adjust the dummy so that the surface area on the forehead immediately adjacent to the projected longitudinal centerline of the test probe is vertical.

(4) Impact the head with the test probe so that at the moment of impact the probe's longitudinal centerline falls within 2 degrees of a horizontal line in the dummy's midsagittal plane.

(5) Guide the probe during impact so that it moves with no significant lateral, vertical, or rotational movement.

(6) Allow a time period of at least 20 minutes between successive tests of the head.

S 572.52 Neck.

(a) The neck consists of the assembly shown in drawing LP 1049/A, and conforms to each of the applicable drawings listed under LP 1049/0 through 54.

(b) When the head-neck assembly is tested in accordance with paragraph (c) of this section, the head shall rotate in its midsaggital plane in reference to the pendulum's longitudinal centerline a total of 85 degrees $\pm$ 6 degrees about its center of gravity, with the chordal displacement measured at its center of gravity not less than 4 inches and not more than 5.6 inches at the maximum rotation. The chordal displacement at time T is defined as the straight line distance between (1) the position relative to the pendulum arm of the head center of gravity at time zero, and (2) the position relative to the pendulum arm of the head center of gravity at time T as illustrated by figure 3 (S 572.11). The peak resultant acceleration recorded at the location of the accelerometers mounted in the headform in accordance with S 572.55(b) shall not exceed 55G.

at 7 fps., the head resultant acceleration measured at the location of the accelerometer mounted in the headform in accordance with S 572.55 (b) shall not be less than 50g and not more than 58g. The recorded acceleration-time curve for this test shall be unimodal at the 20g level and shall lie at, or above that level for an interval not less than 5 and not more than 6.5 milliseconds. The lateral acceleration vector shall not exceed 7.0g.

(c) Test procedure. (1) Seat the dummy on a seating surface having a back support as specified in S 572.55 (g) and orient the dummy in accordance with S 572.55 (g) and adjust the joints of the limbs at any setting between 1 g and 2 g, which just supports the limb's weight when the limbs are extended horizontally forward.

(2) Adjust the test probe so that its longitudinal centerline is at the forehead at the point of orthogonal intersection of the head midsagittal plan and the transverse plane which is perpendicular to the "Z" axis of the head (longitudinal centerline of the skull) and is located ___ $\pm$ 0.1 inches below the top of the head measured along the head's "Z" axis.

(3) Adjust the dummy so that the surface area on the forehead immediately adjacent to the projected longitudinal centerline of the test probe is vertical.

(4) Impact the head with the test probe so that at the moment of impact the probe's longitudinal centerline falls within 2 degrees of a horizontal line in the dummy's midsagittal plane.

(5) Guide the probe during impact so that it moves with no significant lateral, vertical, or rotational movement.

(6) Allow a time period of at least 20 minutes between successive tests of the head.

S 572.52 Neck.

(a) The neck consists of the assembly shown in drawing LP 1049/A, and conforms to each of the applicable drawings listed under LP 1049/0 through 54.

(b) When the head-neck assembly is tested in accordance with paragraph (c) of this section, the head shall rotate in its midsaggital plane in reference to the pendulum's longitudinal centerline a total of 85 degrees $\pm$ 6 degrees about its center of gravity, with the chordal displacement measured at its center of gravity not less than 4 inches and not more than 5.6 inches at the maximum rotation. The chordal displacement at time T is defined as the straight line distance between (1) the position relative to the pendulum arm of the head center of gravity at time zero, and (2) the position relative to the pendulum arm of the head center of gravity at time T as illustrated by figure 3 (S 572.11). The peak resultant acceleration recorded at the location of the accelerometers mounted in the headform in accordance with S 572.55(b) shall not exceed 55G.

(c) Test procedure. (1) Mount the head and neck on a rigid pendulum as specified in Figure 4, (S572.11) so that the head's midsagittal plane is vertical and coincides with the plane of motion of the pendulum's longitudinal centerline. Mount the neck directly to the pendulum as shown in Figure 15. (S572.21)

(2) Release the pendulum and allow it to fall freely from a height such that the velocity at impact is 17.00 $\pm$ 1.0 feet per second (fps), measured at the center of the accelerometer specified in figure 4 (572.11)

(3) Decelerate the pendulum to a stop with an acceleration-time pulse described as follows:

(i) Establish 5g and 20 g levels on the a-t curve.

(ii) Establish t1 at the point where the rising a-t curve first crosses the 5g level, t2 at the point where the rising a-t curve first crosses the 20g level, t3 at the point where the decaying a-t curve first crosses the 20g level and t4 at the point where the decaying a-t curve first crosses the 5g level.
(iii) t2-t1, shall not be more 3 milliseconds.
(iv) t3-t2, shall be not less than 16 and not more than 20 milliseconds.

(v) t4-t3, shall be not more than 7 milliseconds.
(vi) The average deceleration between t2 and t3 shall be not less than 22g and not more than 40g.
(4) Allow the neck to flex without contact of the head or neck with any object other than the pendulum arm.
(5) Allow a time period of at least 30 minutes between successive tests of the head and neck.

S 572.53 Thorax.

(a) The thorax consists of the part of the torso shown in assembly drawing LP 1049/A and conforms to each of the applicable drawings listed under LP 1049/0 through 54.

(b) When impacted by a test probe conforming to S572.21 (a) at 13.0 $\pm$ .3 fps. in accordance with paragraph (c) of this section, the peak resultant accelerations at the location of the accelerometers mounted in the chest cavity in accordance with S 572.55 (c) shall be not less than 65g and not more than 75g. The acceleration-time curve for the test shall be unimodal at or above the 30g level and shall lie at or above the 30g level for an interval not less than 5 milliseconds and not more than 6 milliseconds. The lateral acceleration shall not exceed 7g.

(c) Test procedure. (1) With the completely assembled dummy seated without back support on a surface as specified in S 572.55 (g) and oriented as specified in S 572.55 (g), adjust the dummy arm and legs until they are extended horizontally forward parallel to the midsagittal plane. The joints of the limbs are adjusted at any setting between 1g and 2g, which just supports the limbs weight when the limbs are extended horizontally forward.

(2) Establish the impact point at the chest midsagittal plane so that it is 8.2 inches above the seating surface when the dummy's back is vertical.

(3) Adjust the dummy so that the tangent plane at the surface on the thorax immediately adjacent to the designated impact point is vertical and parallel to the face of the test probe.

(4) Place the longitudinal centerline of the test probe to coincide with the designated impact point and align the test probe so that at impact its longitudinal centerline coincides within 2 degrees with the line formed by intersection of the horizontal and midsagittal plans passing through the designated impact point.

(5) Impact the thorax with the test probe so that at the moment of impact the probe's longitudinal centerline falls within 2 degrees of a horizontal line in the dummy midsagittal plane.

(6) Guide the probe during impact so that it moves with no significant lateral, vertical or rotational movement.

(7) Allow a time period of at least 30 minutes between successive tests of the chest.

S 572.54 Lumbar spine, abdomen and pelvis.

(a) The lumbar spine, abdomen, and pelvis consist of the part of the torso assembly shown in drawing LP 1049/A and conform to each of the applicable drawings listed under LP 1049/0 through 54.

(b) When subjected to continuously applied force in accordance with paragraph (c) of this section, the lumbar spine assembly shall flex by an amount that permits the thoracic spine to rotate from its initial position in accordance with Figure No. 18 of Subpart C by 40 degrees at a force level of not less than 18 pounds and not more than 22 pounds, and straighten upon removal of the force to within 5 degrees of its initial position.

(c) Test procedure. (1) The dummy with lower legs removed is positioned in an upright seated position on a seat as indicated in Figure No. 18, Subpart C, ensuring that all dummy component surfaces are clean, dry and untreated unless otherwise specified.

(2) The pelvis is attached to the seating surface at the hip joints by suitable clamps and the upper legs at the knee rotation joints by the attachment as shown in Figure No. 18 (Subpart C). The mountings are tightened so that the pelvis remains firm and the pelvis-lumbar joining surface is horizontal during the test. The head and neck are removed and in place of the neck is installed a rigid adapter with a pull attachment so that its height at the pull point is equivalent to the neck's height measured at the top center point of the "atlax-axis" block.

(3) Flex the thorax forward 50 degrees and then rearward as necessary to return it to its initial position.

(4) Apply a forward pull force in the midsagittal plane at the top of the neck adapter, so that at 40 degrees of the lumbar spine flexion the applied force is perpendicular to the thoracic spine box. Apply the force at any torso deflection rate between 0.5 and 1.5 degrees per second up to 40 degrees of flexion but no further; continue to apply for 10 seconds the force necessary to maintain 40 degrees of flexion, and record the highest applied force at that time. Release all force as rapidly as possible and measure the return angle 3 minutes after the release.

S 572.55 Test conditions and instrumentation.

(a) The test probe used for head and thoracic impact tests is a cylinder 3 inches in diameter, 13.8 inches long and weights 10 lbs., 6 ozs. Its impacting end has a flat right face that is rigid and that has an edge radius of 0.5 inches.

(b) Accelerometers are mounted in the head on the accelerometer mount (shown in Drawing LP 1049/A so that their seisitive axes intersect at the point of the intersection of a line connecting the longitudinal centerlines of two screws attaching the accelerometer mount in the dummy head with the midsagittal plane of the head. One accelerometer is aligned with its sensitive axis perpendicular to the horizontal bulkhead in the midsagittal plane, another accelerometer is aligned with its sensitive axis parallel to the horizontal bulkhead6and perpendicular to the midsagittal plane, and a third accelerometer is aligned with its sensitive axis parallel to the horizontal bulkhead in the midsagittal plane. The seismic mass center of any of these accelerometers is at any distance up to 0.4 inches from the axial intersection point.

(c) Accelerometers are mounted in the chest cavity on the provided mount located on the vertical frontal surface (hereafter "attachment surface") of the thorax assembly so that their sensitive axis intersect at the point in the thorax midsagittal plane located _____ inches above the transverse bottom surface of the chest cavity and ___ inches aft of the frontal vertical surface of the chest cavity. One accelerometer has its sensitive axis oriented parallel to the attachment surface in the midsagittal plane, another accelerometer has its sensitive axis oriented parallel to the attachment surface and perpendicular to the midsagittal plane and a third accelerometer has its sensitive axis oriented perpendicular to the attachment surface in the midsagittal plane. The seismic mass center of any of these accelerometers is at any distance up to 0.4 inches from the axial intersection point.

(d) The outputs of acceleration devices installed in the dummy and in the test apparatus specified by this part are recorded in individual data channels that conform to the requirements of SAE Recommended Practice J211, June 1980, with channel classes as follows:

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(1) Head acceleration-Class 1000.

(2) Pendulum acceleration-Class 60.

(3) Thorax acceleration-Class 180.

(e) The mountings for sensing devices shall have no resonance frequency within a range of 3 times the frequency range of the applicable channel class.

(f) Limb joints are set at 1g, barely restraining the weight of the limb when its is extended horizontally. The force required to move a limb segment does not exceed 2g throughout the range of limb motion.

(g) Performance tests are conducted at any temperature from 66 degrees F to 78 degrees F and at any relative humidity from 10 percent to 70 percent after exposure of the dummy to these conditions for a period of not less than 4 hours.

For the performance tests specified in S 572.51, 572.53, and 572.54 the dummy is positioned in accordance with Figures No. 16, 17 and 18 of the Subpart C as follows:

(1) The dummy is placed on a flat, rigid, clean, dry, horizontal surface of teflon sheeting with a smoothness of 40 microinches and whose length and width dimensions are not less than 16 inches, so that the dummy's midsagittal plane is vertical and centered on the test surface. For head tests, the seat has a vertical back support whose top is 10.3 $\pm$ 0.2 inches above the seating surface. The rear surfaces of the dummy's back and buttocks are touching the back support as sown in Figure No. 16. For thorax and lumbar spine tests, the seating surface is without the back support as shown in figures No. 17 and No. 18 .

(2) The dummy is adjusted for head and thorax impact tests and for lumbar flexion tests so that the rear surfaces of the shoulders and buttocks are tangent to a transverse vertical plane.

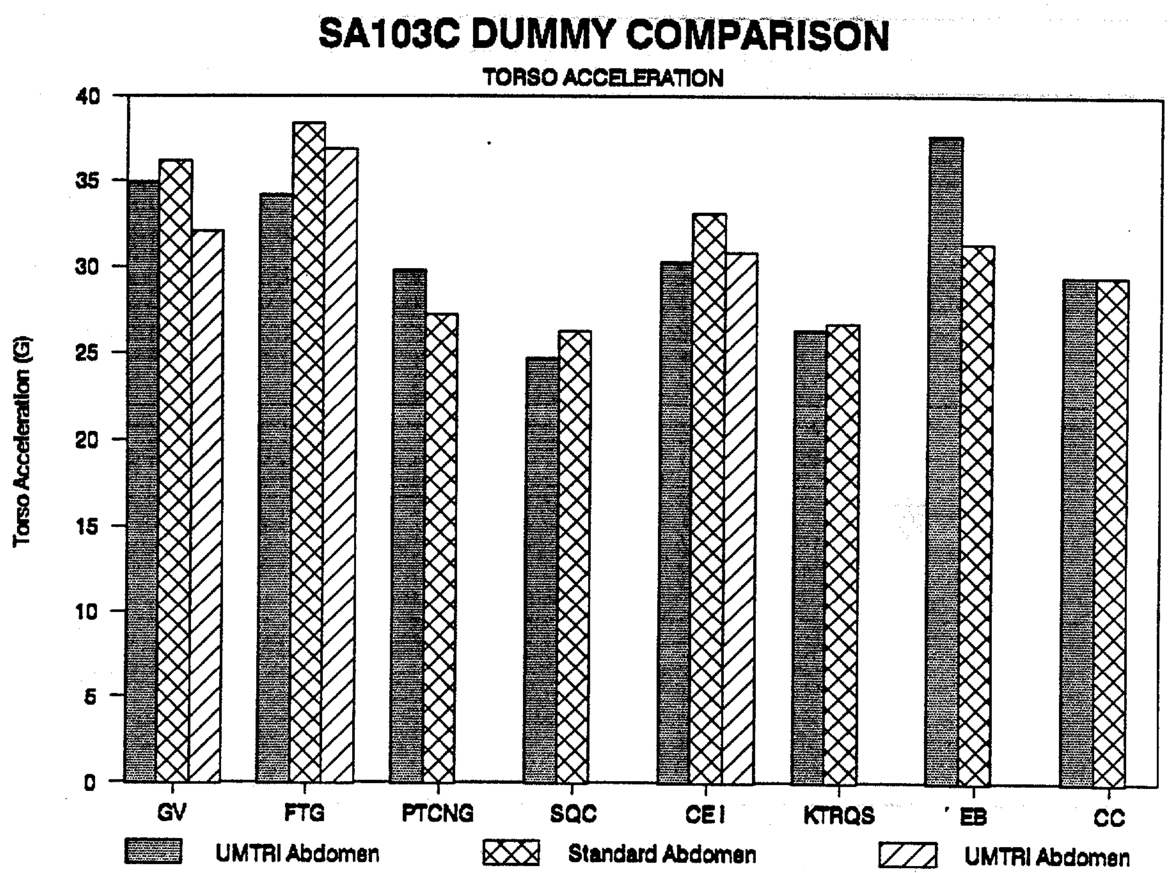
(3) The arms and legs are positioned so that their centerlines are in planes parallel to the midsagittal plane.

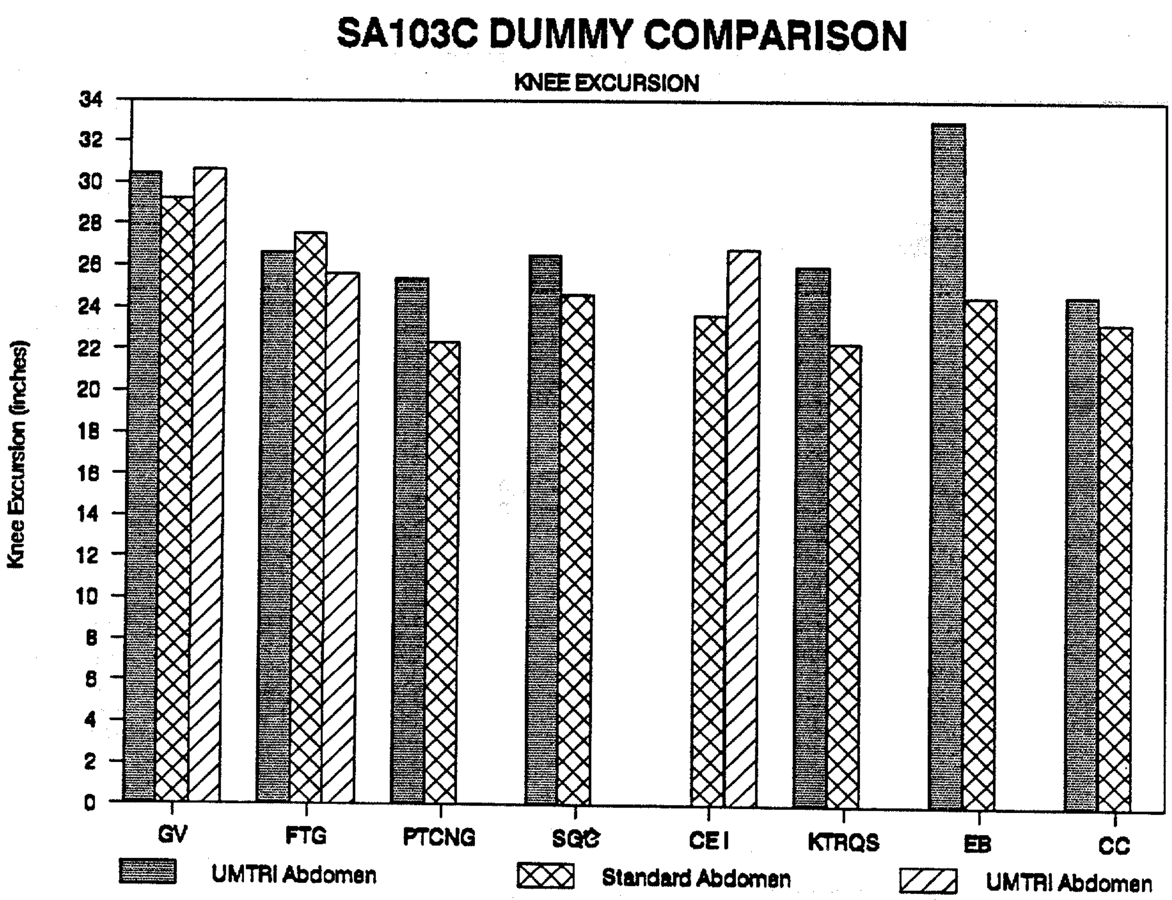
(h) Performance tests of the same component, segment, assembly or fully assembled dummy are separated in time by a period of not less than 20 minutes unless otherwise specified.

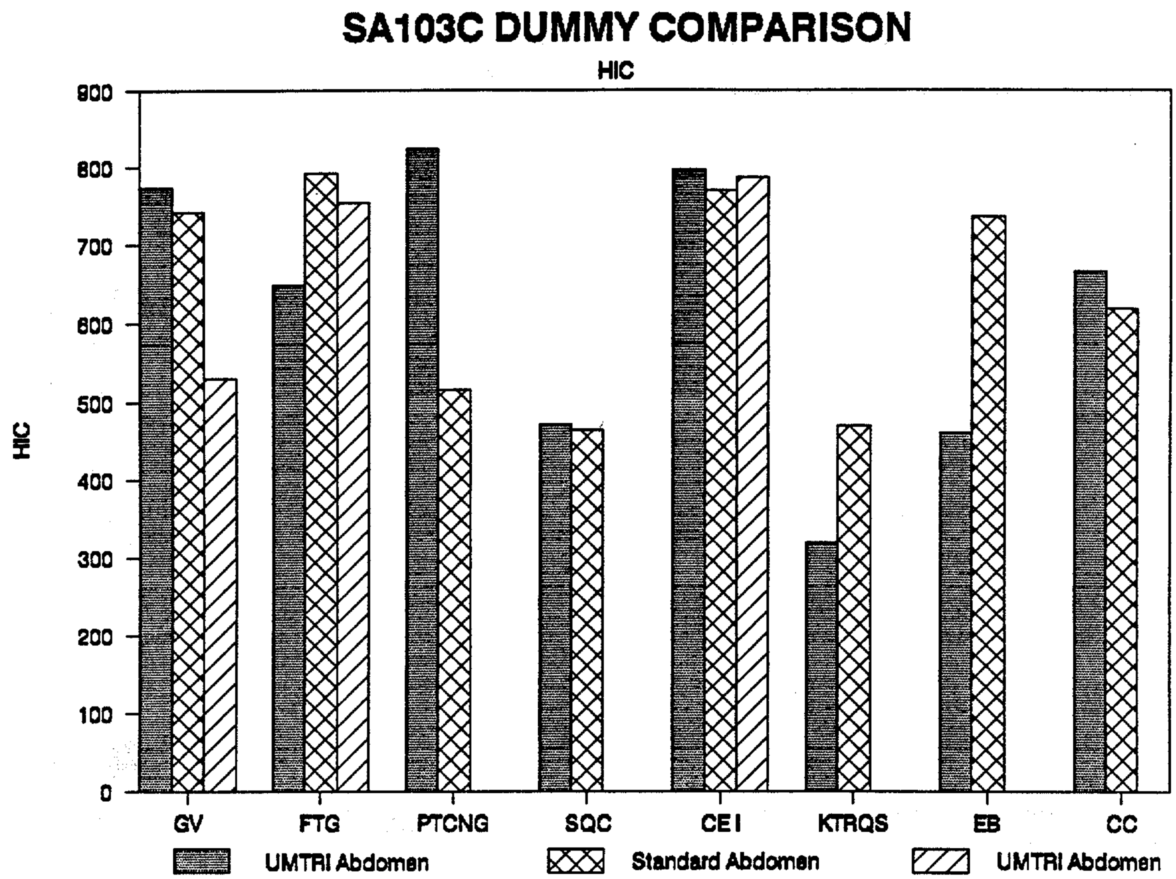
(i) Surfaces of the dummy components are not painted except as specified in this part or in drawings subtended by this part.

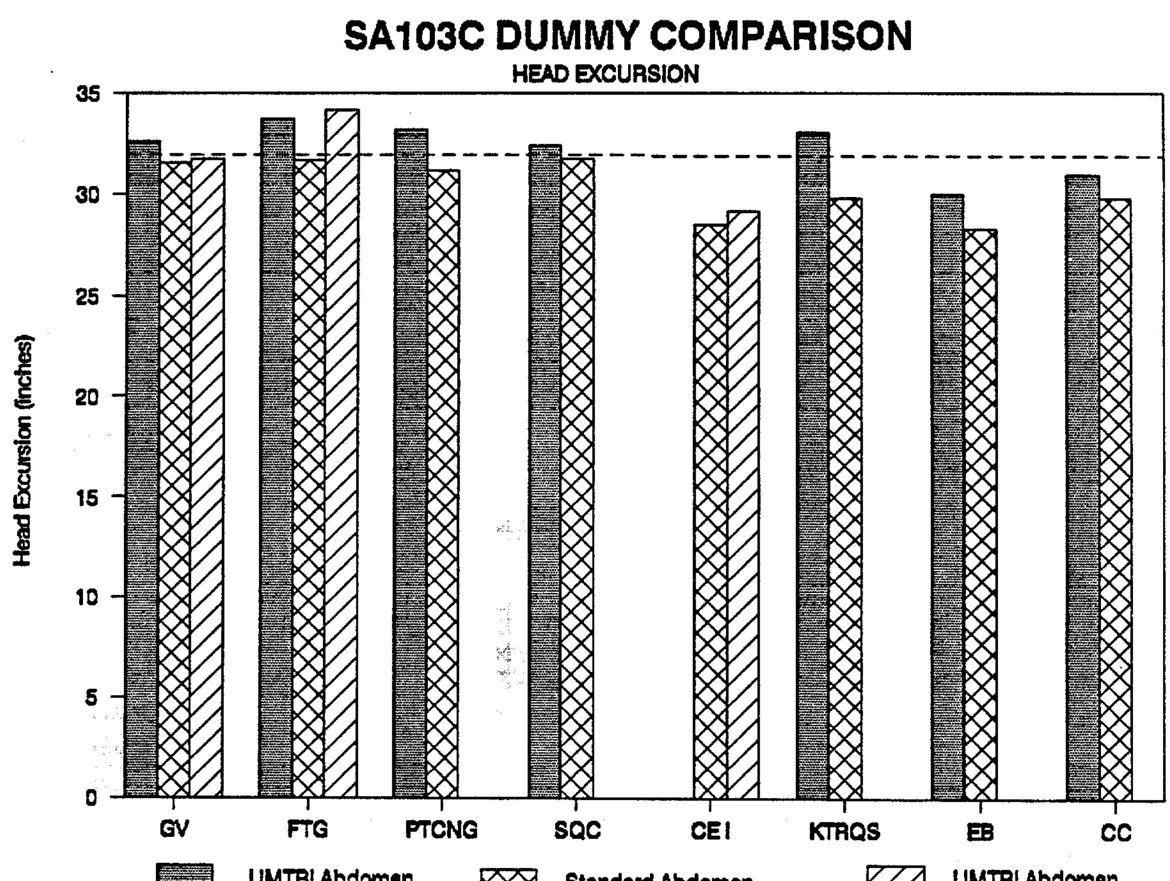
APPENDIX B

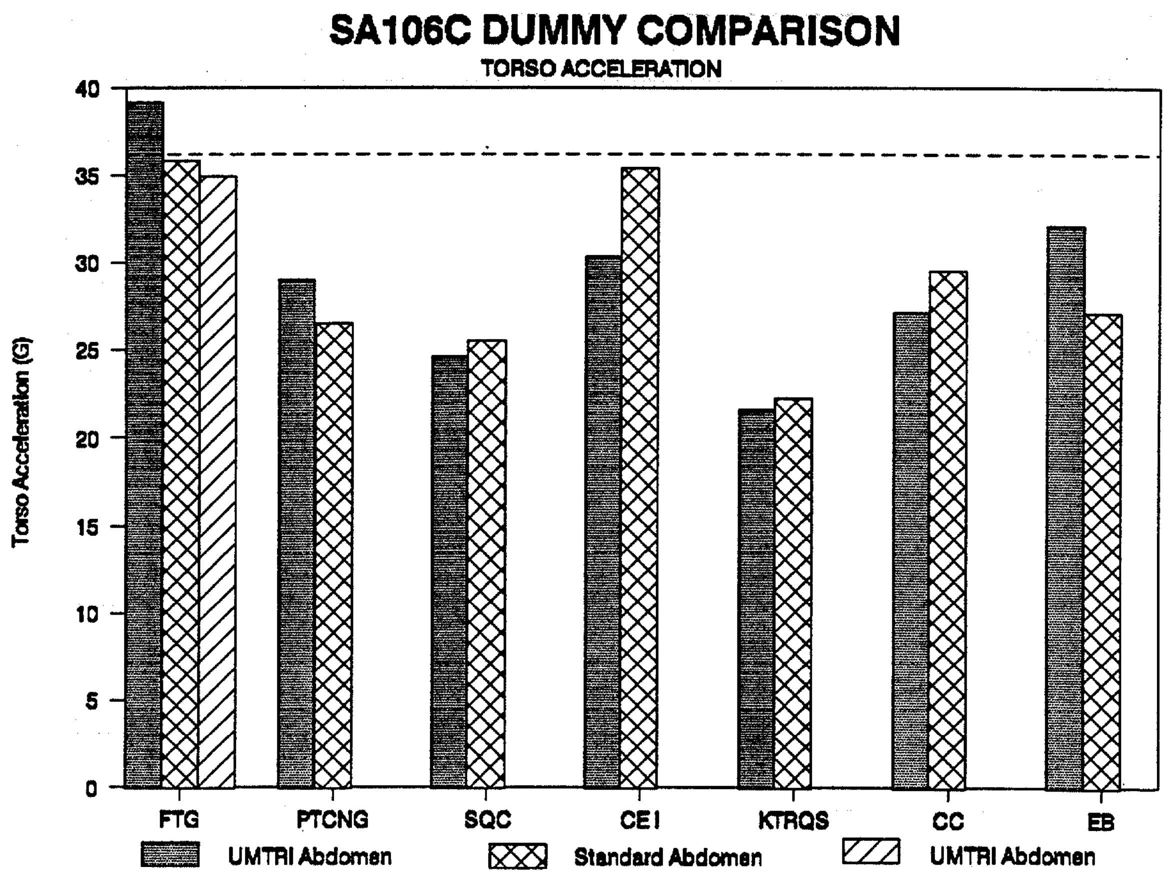
Dummy Comparison Results


SA103C DUMMY COMPARISON
TORSO ACCELERATION
Torso Acceleration (G)
40
35
30
25
20
15
10
5
0
GV
FTG
PTCNG
SQC
CE I
KTRQS
EB
CC
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen

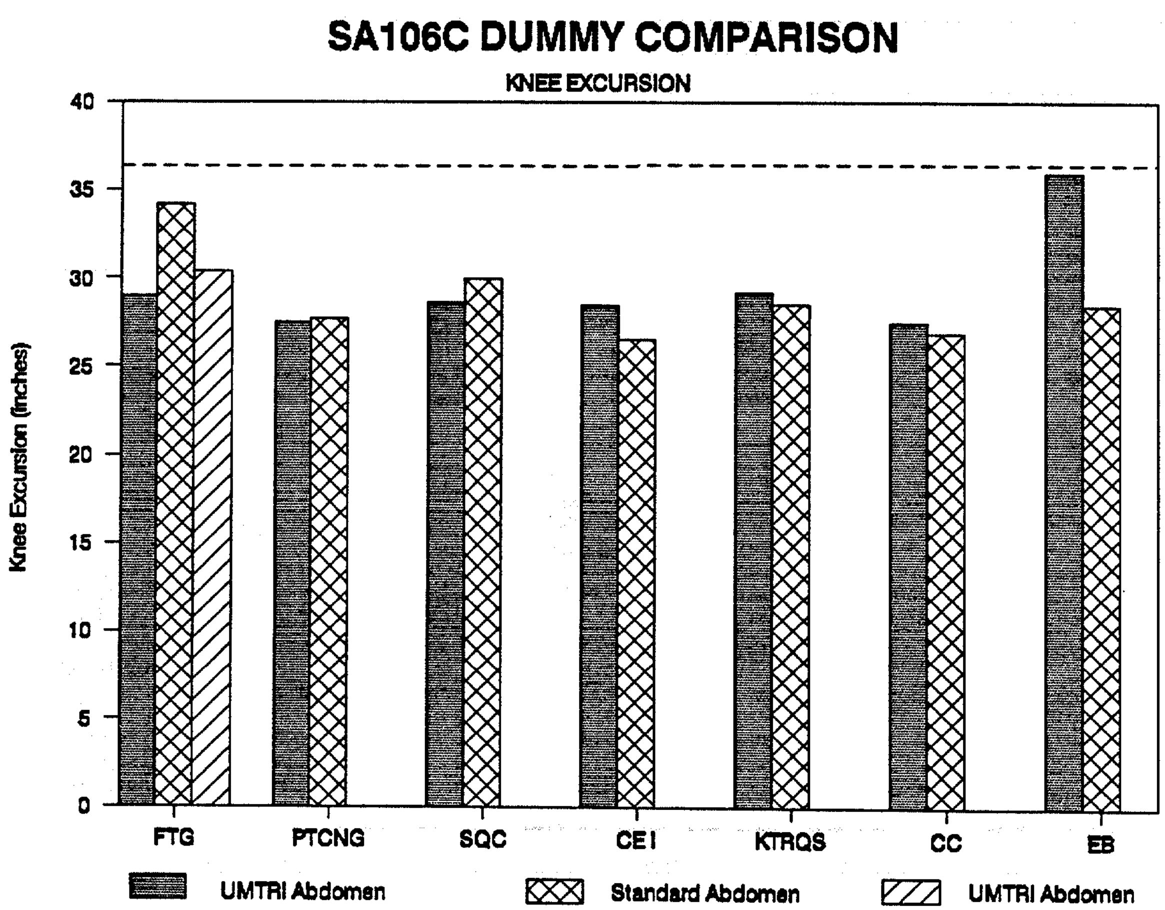

SA103C DUMMY COMPARISON
KNEE EXCURSION
Knee Excursion (inches)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
GV
FTG
PTCNG
SQC
CE I
KTRQS
EB
CC
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen


SA103C DUMMY COMPARISON
HIC
HIC
900
800
700
600
500
400
300
200
100
0
GV
FTG
PTCNG
SQC
CE I
KTRQS
EB
CC
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen

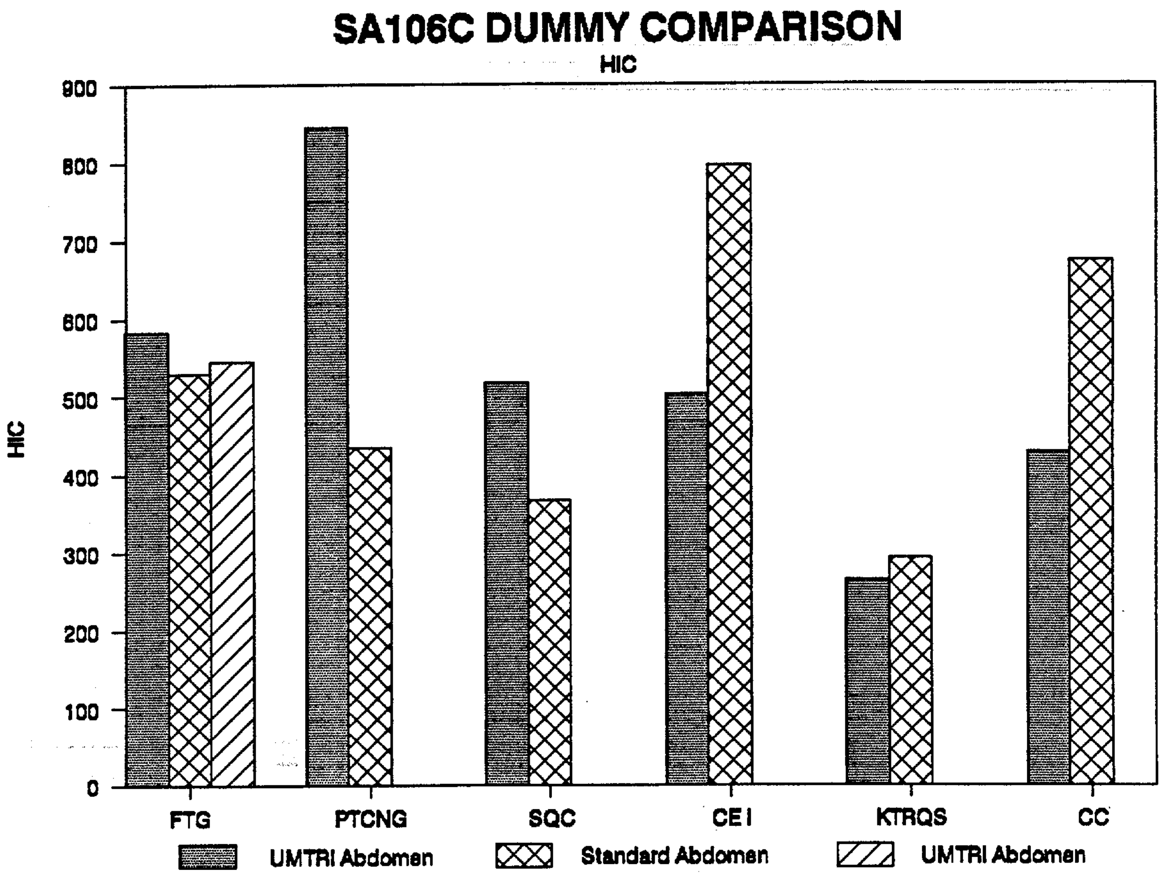

SA103C DUMMY COMPARISON
HEAD EXCURSION
Head Excursion (inches)
35
30
25
20
15
10
5
0
GV
FTG
PTCNG
SQC
CE I
KTRQS
EB
CC
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen

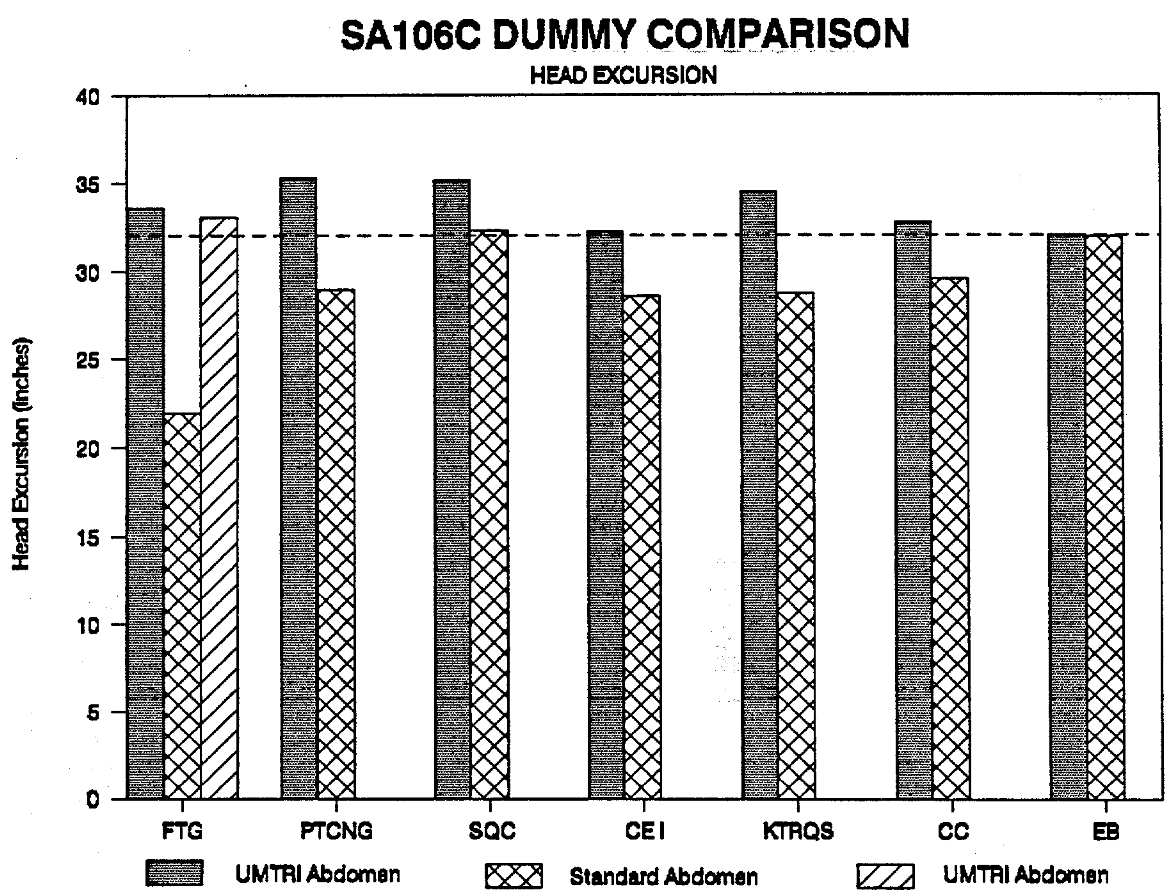


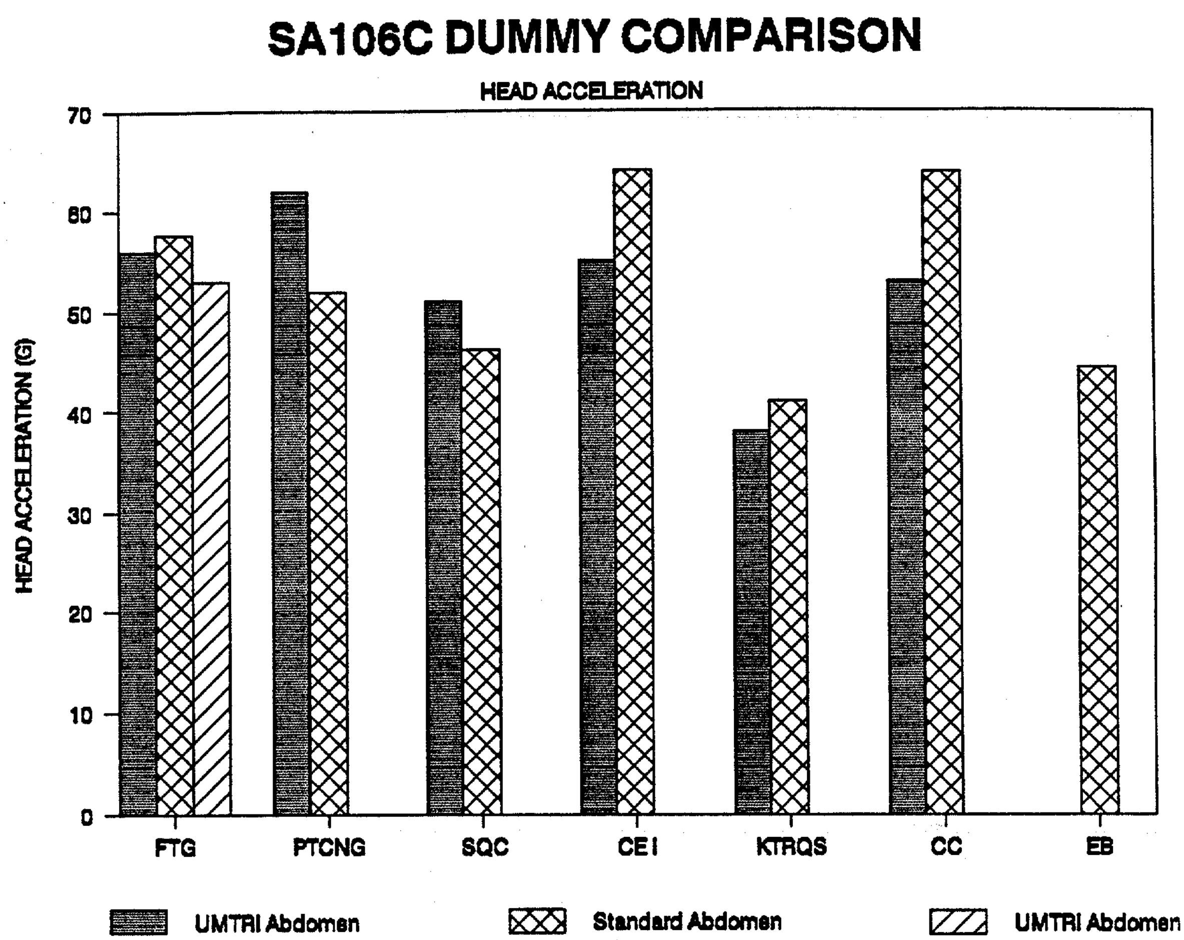
SA106C DUMMY COMPARISON
TORSO ACCELERATION
Torso Acceleration (G)
40
35
30
25
20
15
10
5
0
FTG
PTCNG
SQC
CE I
KTRQS
CC
EB
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen



SA106C DUMMY COMPARISON
KNEE EXCURSION
Knee Excursion (inches)
40
35
30
25
20
15
10
5
0
FTG
PTCNG
SQC
CE I
KTRQS
CC
EB
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen


SA106C DUMMY COMPARISON
HIC
900
800
700
600
500
400
300
200
100
0
HIC
FTG
PTCNG
SQC
CE I
KTRQS
CC
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen


SA106C DUMMY COMPARISON
HEAD EXCURSION
40
35
30
25
20
15
10
5
0
Head Excursion (inches)
FTG
PTCNG
SQC
CE I
KTRQS
CC
EB
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen


SA106C DUMMY COMPARISON
HEAD ACCELERATION
HEAD ACCELERATION (G)
70
60
50
40
30
20
10
0
FTG
PTCNG
SQC
CE I
KTRQS
CC
EB
UMTRI Abdomen
Standard Abdomen
UMTRI Abdomen